DOCTOR OF PHILOSOPHY

Critical Success Factors for Lean Construction Intervention

Ward, Steven Anthony

Award date:
2015

Critical Success Factors for Lean Construction Intervention

by

Steven Anthony Ward

A thesis submitted in fulfillment of the requirements

for a degree of Doctor of Philosophy in the

Division of Civil Engineering of

The University of Dundee

August 2015

TABLE OF CONTENTS

Chapter 3 Methodology

Chapter 6 – Conclusions And Recommendations

Appendixes

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BIM	Building information modelling
BIS	Department for business innovation and skills
BPR	Business process re-engineering
BRE	Building research establishment
CLIP	Construction lean improvement programme
CSF	Critical success factor
DTI	Department of trade and industry
EFQM	European foundation for quality management
IGLC	International group for lean construction
JIT	Just in time
LCI	Lean construction institute
LPS	Last planner system
OEE	Overall equipment effectiveness
PDCA	Plan – do – check - act
POOGI	Process of on-going improvement
SME	Small or medium size enterprise
SMED	Single minute exchange of dies
SMMT	Society of motor manufacturers and traders
SPC	Statistical process control
TFV	Transformation flow value theory
TOC	Theory of constraints
TPM	Total productive maintenance
TPS	Toyota production system
TWI	Training within industry
TQM	Total quality management
UK	United Kingdom
WIP	Work in progress

ACKNOWLEDGEMENTS

It has been the greatest honour to work under the supervision of Professor Malcolm Horner, the guru of productivity. Patient but industrious, he has contributed some of his wisdom and precision without which completion would have been impossible. A wonderful mentor, colleague and friend.

This work would not exist without the time given by the thirty-seven lean construction practitioners that agreed to in depth interviews; space does not allow for all to be listed here but they appear in Appendix Two. Special thanks go to Andrew Taylor of ISG plc, who helped me "find my voice" in the early days and all my old colleagues at Pearce Group and to Steven Allan of Tayside Contracts, whose example of dogged determination helped me keep going.

Thanks for the help from my friend the late Richard Donnelly, who as both a chartered architect and former factory manager serving the automotive sector, possessed unique insight into lean construction now sadly lost, and to my colleagues at 6ix Consulting, Michelle Leong and Andrew McElwee.

Thanks to the staff at Dundee University, for making me feel welcome. To Andy Munns, in particular, for helping me with coding and narrative analysis, Doug Forbes for advice on statistical methods and Mohamed ElHaram for convincing me not to give up. To Geoff Wood, for his word-processing skills, suggestions and proofreading.

The final version of this thesis was improved with the benefit of the examiners comments and thanks are due to Professor Lauri Koskela and Dr Tom Dyer.

Finally, to my wife Katrina, son Daniel and daughter Megan who have suffered from a lack of attention from me during this work, particularly over the last six months.

Declaration

I hereby declare that this thesis has been compiled by me, that it is a record of work completed by me, and that is has not previously been accepted for a higher degree at this University or any other institution of learning.

S. A. Ward

……………………………….

Steven Anthony Ward

Certificate

This is to certify that Steven Anthony Ward has done this research under my supervision, and that he has fulfilled the conditions of Ordinance 14 of the University of Dundee, so that he is qualified to submit for the degree of Doctor of Philosophy.

……………………………….

R. Malcolm W. Horner

Professor of Engineering Management

Ward.Steven.A Critical success factors for lean construction intervention. University of Dundee 2016

ABSTRACT

Despite the successful application of lean thinking across a wide range of industries, and a number of UK Government funded programmes such as the Construction Lean Improvement Programme and Constructing Excellence, the construction sector lags behind other sectors as highlighted in the Egan Report (1998) and more recently in Sir John Egan's speech to the House of Commons in 2008 which gave the construction industry "four out of ten – for trying."

This led to the research question: *What are the critical success factors for lean construction interventions?*

The emergence of lean production as a concept and the contributions of its key historic influencers are explored. Differences between construction and manufacturing are compared and discussed, and it is concluded that there is no practical reason why lean production cannot be successfully applied to construction operations. However, the issue of buildings being "rooted-in-place" is a potential barrier to true global competition.

Progress was made towards a satisfactory definition of lean construction, a term hitherto ill-defined. Nineteen potential critical success factors (CSF) were identified in a literature review. A pilot study conducted with senior construction staff experienced in lean construction identified a further seven potential critical success factors and discounted three derived from the literature. Face-to-face interviews with thirty-one construction staff that had attempted lean construction interventions were conducted to examine the significance of each factor. Of the interventions, twenty-six were successful and six were failures. Statistical analysis compared the failure and success groups and of a total of twenty-three factors examined, thirteen were critical, two important, seven not critical and one unknown.

Some of the most cited lean critical success factors, for example "There must be a crisis", were shown to be not significantly important for the construction sector. Interdependencies between the statistically significant factors were explored and it was concluded that a wide concern with "getting buy-in" exists. Three factors appeared to possess a greater ability to influence all the others: the capability of management; client influence; and the right facilitator.

KEY WORDS

Lean Construction, Critical Success Factors, Intervention, Definition

CHAPTER 1 - INTRODUCTION

1.1 Lean thinking – an industrial imperative

The performance gap between manufacturing businesses that adopt lean thinking and those that do not is extraordinary (Womack, Jones and Roos 1990). Similar performance gaps can also be observed in the construction sector. A report commissioned by the European Parliament found that overall resource utilisation in construction in the United Kingdom (UK) was 30 per cent lower than the best performing countries (Bernard Williams Associates (BWA) 2006). Even locally between different gangs working on similar tasks for the same company, variations in productivity of 75 per cent have been measured, whilst productivity differences in apparently similar tasks on different sites can be as much as 500 per cent (Horner and Duff 2001). If contractors in the UK were able to improve productivity by 25 per cent, this could lead to a four-fold improvement in profit margin or enable re-investment into the sector to the tune of 6 per cent of UK construction spend (Horner and Duff 2001).

In 2014 the construction industry in the UK contributed £92 billion in economic output and employed around 2 million people (Rhodes 2015). The construction strategy 2025 (Department for Business, Innovation and Skills (BIS) 2013) sets highly ambitious targets for improvement, calling for cost savings of 33 per cent, time savings of 50 per cent together with a 50 per cent reduction in emissions and higher exports. It does not however provide any real guidance as to the means by which this will be achieved, apart from a heavy reliance on new technology in the form of Building Information Modelling (BIM). This is what Deming (1986) would have decried as “management by objective”: in other words stating a numeric goal without specific means by which it can be achieved. There have been many reports from the UK government about improving the construction sector and one of the most significant to this research is the Egan Report (1998) that highly influenced the birth of several concerted efforts to improve the UK construction sector including Constructing Excellence and the subsequent development of the Key

Performance Indicators for Construction (Glenigan 2014). The Building Research Establishments' Construction Lean Improvement Programme - CLIP (Department for Trade and Industry (DTI) 2006), funded by the then Department for Trade and Industry, is one of 14 other "adopter" programmes covering most other business sectors in the UK. CLIP began using a "Common Approach" to continuous improvement originally developed by the Society of Motor Manufacturers and Traders (SMMT) Industry Forum for use in the UK automotive and aerospace supply chains (DTI, 2006). It could be assumed that the purpose of a "common approach" was to achieve a "common result", however this has not been realised. Whilst there have been many successes, some spectacular in nature, there have also been many failures and the sector as a whole has failed to grasp the nettle. It has been stated that the definition of insanity is doing things the same way but expecting a different outcome – perhaps the UK construction sector needs another report with some new targets then?

1.2 Useful work to date

Despite a general lack of improvement, significant advances have been made in the field of lean construction over the last 15 years or so. Accepted production and project management theories have been challenged, new lean construction tools have emerged and some practical advice for industry has been provided (Ballard 2000a; Ballard 2000b; Horner and Duff 2001; Howell 1999; Koskela 2000). In addition, direct translations of classic lean manufacturing techniques have been demonstrated to work successfully in a number of different construction settings (Pereira 1998; Ward and McElwee 2007).

There is now a significant body of literature available from the International Group for Lean Construction (IGLC) and good, although arguably often anecdotal evidence that the application of lean construction can significantly improve performance.

1.3 Background to the research and the researcher's profile

The researcher has a total of 38 years of construction industry experience in various roles from apprentice carpenter through to chartered builder and latterly lean construction consultant. The last role directly within industry was as "Innovation manager", with the main innovation being the practical application of lean construction. In 2004 the researcher joined the Construction Lean Improvement Programme where he was trained by master automotive lean engineers in the Toyota Production System. He has studied and practically applied in industry the work of Deming, Juran and Goldratt and also holds formal qualifications in lean thinking and process improvement, e.g. six sigma blackbelt and business improvement techniques. He authored the first UK vocational qualification in lean construction whilst working for the BRE in 2006. Currently serving as the Managing Director for 6ix Consulting Ltd, he has 13 years hands on experience as a lean construction consultant. As a result, access to a rich data source in the form of case studies and construction personnel that have been involved in lean interventions was readily available.

1.4 Gaps in Knowledge

In 2005 the researcher led a lean construction intervention surrounding the on-going refurbishment and maintenance of a high tech electrical manufacturing plant. The facilitation input was minimal and consisted mainly of one day of on-site training followed by a limited amount of mentoring. At a follow-up one year later the improvement team involved had managed to achieve over £500,000 of quantifiable savings from their improvements on the original site and had also been able to rollout some of the key techniques taught across most other live projects. The savings from all the other projects could not be quantified. In contrast, another contractor that was seeking to apply lean thinking to its business during the same period achieved very modest improvements to just one project despite a significant level of support. This example begs the question: "What were the differences between the two situations that led to one being significantly more successful than the other”. This leads to the research question: *What are the critical success factors for lean construction intervention?*

Lean thinking is certainly a conceptual term; what does it really mean? How would one know if a construction project or service was lean or not? If it means more for less, how much more for how much less does it need to be to qualify as lean? There exists a wide variety of unsatisfactory definitions of what lean thinking actually is, and no existing definition is able to describe lean construction with any rigorously testable method (Dauber 2003; Green and May 2005). A failure to articulate the concept in a way the industry can understand may well be a major obstacle to the successful deployment of lean construction.

1.5 Aims and objectives

1.5.1 Aims

The main aim of this research is to provide guidance to better inform future efforts in deploying lean construction, both at a local interventional level and more strategically for the sector as a whole by identifying those factors that are critical in embedding lean thinking within a construction organisation. In this way it may be possible to better inform how lean construction interventions should be approached, make it more relevant to the needs of the construction sector, and be able to identify situations where it is worth pursuing an interventional type improvement project based on lean thinking in preference to other approaches.

1.5.2 Objectives

Articulation of the aims led to the following objectives:

1. Explore the emergence of lean production as a concept and contributions of its key historic influencers.

2. Work towards an operational definition of lean production by exploring the features that differentiate lean from other improvement methods.

3. Examine the differences between production and construction and work towards an operational definition of lean construction.

4. Elicit from the literature those factors that are considered critical for success.

5. Test the relevance of those factors identified in the literature by conducting interviews with construction professionals in a pilot study.

6. Capture any new factors emerging from the pilot study.

7. Design a suitable research methodology to test the relative importance of each of the factors.

8. Derive from the results the implications for industry.

9. Produce summary guidance based on the research

1.6 Thesis Structure

This thesis is about lean construction, but more specifically the adoption of lean construction. Contextual background is provided in Chapter 2, which covers the developmental history of lean thinking in industry generally and works toward defining it, before following the same pattern for lean thinking in construction. Differences between lean manufacturing and lean construction are compared and discussed. Critical success factors necessary for lean construction intervention are examined. In Chapter 3 methods for testing for the presence or absence of these factors are discussed and selected, a pilot study conducted and new factors found. Twenty-three hypotheses are formed to carry forward into the main study.

The initial results are reported in Chapter 4 and fully discussed in Chapter 5, where interdependencies between the factors are considered and the likelihood of the most influential factors discussed. Some of the factors discovered in the literature are shown to be not significant when tested in industry and new factors are added from the pilot study that did prove significant. A revised set of results is offered at the end of Chapter 5 after a triangulation process between the literature review, pilot study, main study and analysis. Conclusions are drawn, recommendations for future research are made and the guidance for industry produced in Chapter 6.

CHAPTER 2 – LITERATURE REVIEW

2.1 What Is Lean?

The concept of Lean Production was popularised in 1990 by the book "The Machine that Changed the World" (Womack, Jones and Roos 1990), and since this publication worldwide interest in the subject has increased, with a plethora of books, publications, conferences, dissertations and theses generated. Virtually all of the literature on lean thinking point to the Toyota Motor Corporation as the exemplar of lean production.

However, the roots of lean production go much further back, and in order to establish the context a brief history of the evolution of lean production and key innovations is presented.

2.1.1 Eli Whitney Jr.

Whilst it remains an area for discussion, Eli Whitney has been credited with the beginning of efficient American manufacturing, combining for the first time powered machinery, the division of labour and interchangeable parts in the manufacture of armaments from 1798 (Woodbury 1960).

2.1.2 F.W. Taylor

In the book "The Principles of Scientific Management" published in 1911 (Taylor 1911), Taylor describes a four-step approach to productivity improvement that proved successful for those that applied it correctly. In one cited example, output for loading iron was increased from 12.5 to 47 tons per man per day. Taylor (1911: 36-37) prescribes a new role for management whereby:

″First. They develop a science for each element of a man's work, which replaces the old rule- of-thumb method.

Second. They scientifically select and then train, teach, and develop the workman, whereas in the past he chose his own work and trained himself as best he could.

Third. They heartily cooperate with the men so as to insure all of the work being done is in accordance with the principles of the science that has been developed.

Fourth. There is an almost equal division of the work and the responsibility between the management and the workmen. The management take over all work for which they are better fitted than the workmen, while in the past almost all of the work and the greater part of the responsibility were thrown upon the men″.

Taylor (1911: 140) goes on to crystallise his philosophy:

1. "Science, not rule of thumb.
2. Harmony, not discord.
3. Cooperation, not individualism.
4. Maximum output, in place of restricted output.
5. The development of each man to his greatest efficiency and prosperity."

Taylor has been highly criticised for adopting an alleged inhuman approach. However, it is noted that the men who worked under Taylor's scientific guidance earned significantly more than those that did not, with bonuses for achieving doable productivity targets of between 30 and 100 per cent of basic wages, and in one example, after leaving Taylor's project for a higher basic day rate, the men returned as they were not able to produce or earn nearly as much as when working under Taylor's guidance.

References to “Taylorism” appear in the Lean Construction literature and it would seem that this is viewed as generally demeaning and bad for workers. It is considered here that the authors of such literature could not have actually read Taylor’s work themselves for the following reason.

It can be observed that the Taylor philosophy as described above was largely overlooked or deliberately ignored by industry at large, with enhanced profits from efficiency/productivity gains generally not benefitting the worker as recommended by Taylor but going instead to the owners or shareholders, a lack of co-operation between worker and management, discord instead of harmony and rule of thumb over science (Green 1999). This is surprising given the factual evidence of gains for all parties presented by Taylor, and perhaps presents a clue to why many business change programmes fail. It is also the case that Step 1, *Developing a Science for each element of work,* clearly links to both the work of Training Within Industry – TWI (Gaupp and Wrona 2006) and Toyota’s standardised work technique as discussed by Taiichi Ohno (Ohno 1988). These methods involve direct observation of the work, which is then analysed, improved and documented.

2.1.3 Frank and Lillian Gilbreth

Frank Gilbreth is of particular interest in any discussion of Lean Construction as he is perhaps the only forefather of Lean Thinking that actually worked in the construction industry. As a building contractor, he sought ways to make bricklaying (his first trade) faster and easier (Gilbreth 1909). Gilbreth managed to vastly improve the productivity of bricklaying using his techniques for reducing motion. Subsequently, this grew into collaboration with his eventual wife Lillian Gilbreth, who studied the work habits of manufacturing and clerical employees in a range of industries to find ways to increase output and make their jobs easier. Frank Gilbreth was the first to propose that a surgical nurse serve as "caddy" (Gilbreth's term) to a surgeon, by handing surgical instruments to the surgeon when required (Management Library 2012). Gilbreth also devised the standard techniques used by armies around the world to teach recruits how to rapidly disassemble and reassemble their weapons even when blindfolded or in total darkness (New World Encyclopedia 2013). Frank Gilbreth is also credited with the introduction of graphical representations of workflows known as "Process Charts".

In 1907, Frank met Frederick Winslow Taylor and became an admirer of the Taylor System of time study. The Gilbreths became deeply involved in scientific research and Frank was instrumental in creating the Taylor Society (Ricci 2012). In 1912, the Gilbreths left construction and focused their attention on scientific management consulting. They broke with Taylor in 1914 and created their own form of scientific management, which focused on the human element as well as the technical. In 1915, Lillian received her doctorate in psychology and incorporated her training into the family business. She and Frank saw the need to improve worker satisfaction, which would in turn improve overall job performance and worker efficiency. Frank designed systems to ease worker fatigue and increase productivity by studying each movement a worker made in a process he called micromotion study (Ricci 2012). This led to his codification of types of movement into his “18 Therbligs” (Gilbreth and Gilbreth 1948) later used to great effect by Shingo (2007).

The Gilbreths used still photographs and filmstrips to study worker movements in order to devise the “One Best Way” to perform a task. They also saw the need to improve the physical comfort of the worker, and their innovations in office furniture design were ahead of their time, leading the way to the study of ergonomics. The direct relationship to the elimination of some of Taiichi Ohno's classic seven wastes can be observed (Ohno 1988). Further, many of the more current practical Lean tools and techniques appear to have their roots in the work of Taylor and Gilbreth, including 5S workplace organisation, Direct Observation and Standardised Work taught by the American consultancy Training Within Industry (Bicheno 2000).

2.1.4 Henry Ford

It is recognised in the literature that Ford's Model T plant was the first major application of lean production (Womack and Jones 1996; Liker 2004). At Ford they took all the elements of a manufacturing system - people, machines, tooling, and products - and arranged them in a continuous flow system for manufacturing the Model T automobile, which Ford had observed as being effective in a meat processing plant. Ford also employed F.W. Taylor as a consultant. Productivity of the Model T was improved from 1 car every 12 hours to 1 every 1.5 hrs at the Highland Park Plant, and then in the new Dearborn plant to 1 every 24 seconds. Ford was so incredibly successful he quickly became one of the world's richest men and put the world on wheels. Ford is considered by many to be the first practitioner of Just in Time and Lean Manufacturing. His approach worked brilliantly when applied to a single repeatable product (you could have a Model T in any colour you liked as long as it was black!) but eventually began to fail when the market began to demand more variety and consumer choice and customisation.

Ford's book "Today and Tomorrow" published in 1926 (Ford 1926) is credited as a great inspiration to Taiichi Ohno, founder of the Toyota Production System (TPS) (Ohno 1988).

2.1.5 Walter A. Shewhart

Shewhart was a physicist brought into the early telephone industry by Bell Telephone Laboratories to solve a particular business problem, namely unpredictable failure rates of components in underground installations (Shewhart 1931; Shewhart 1939). Shewhart's work pointed out the importance of reducing variation in a manufacturing process and understanding that continual process-adjustment in reaction to non-conformance actually increased variation and degraded quality. Deming later called this "tampering" and "mistake (a)" and described it as reacting to a common cause of variation as though it were a special cause (Deming 1986).

Shewhart made a pivotal contribution to quality improvement by splitting variation into two broad types - assignable-cause and chance-cause variation – and introducing the control chart as a tool for distinguishing between the two. Shewhart stressed that bringing a production process into a state of statistical control, where there is only chance-cause variation, and keeping it in control, is necessary to predict future output and to manage a process economically. Dr. Shewhart created the basis for the control chart and the concept of a state of statistical control by carefully designed experiments. While Dr. Shewhart began from mathematical statistical theories, he understood that data from real manufacturing processes rarely produced a "normal distribution curve" (a Gaussian distribution, also commonly referred to as a "bell curve"). Primarily by direct observation and empirical research, the purpose of which was to solve real industrial problems, he discovered that observed variation in data gathered from manufacturing processes did not always behave the same way as data in nature, for example Brownian motion of particles which displays random variation. Dr. Shewhart concluded that while every process displays variation, some processes display common variation that is natural to the process, while others display special variation that is not present in the process causal system at all times.

Shewhart worked to advance the thinking at Bell Labs from their foundation in 1925 until his retirement in 1956, publishing a series of papers in the *Bell System Technical Journal (Shewhart 1928-1954).* His work was summarised in his book "*Statistical Method from the viewpoint of Quality Control"* (Shewhart 1939). This greatly influenced the future work of quality gurus Deming and Juran.

2.1.6 Deming

Deming was primarily a statistician and a loyal student of the work of Walter Shewhart. (Deming 1986) Deming visited Japan in 1948 and started working with Japanese industry shortly afterwards. He taught a theory of management which was codified as his fourteen points for management and his seven deadly diseases. This later crystallised into his "Theory of Profound Knowledge" (Deming 1994). This consisted of four elements:

1. Appreciation of a system - Here Deming emphasised that it is folly to focus on optimisation of any individual asset at the expense of the overall aim of the system.

2. Understanding Variation - This was primarily focused on the use of Statistical Process Control, invented by Shewhart to monitor and improve quality.

3. A "Theory of Knowledge" - This is derived from two key Shewhart concepts:

    a. About clear communication of meaning and specification, a concept called "operational definitions".

    b. The Shewhart Cycle of "Plan, Do, Study, Act".

4. Psychology - Deming believed that intrinsic rather than extrinsic motivation was the key to occupational psychology; Deming was an advocate of Kohn's work on motivation theory (Kohn 1999).

Deming taught primarily to focus on the process, not the person. Of interest, he was not a great fan of "Just in Time" production, where material stocks are kept to a bare minimum and arrive just before they are actually needed, calling it "Just in Case". Many academics and consultants attribute the transformation of post war Japanese industry to Deming (Womack and Jones 1996; Liker 2004).

2.1.7 Juran

Juran appears to have followed a similar path to Deming, being heavily influenced by the work of Shewhart at Bell Telephone Laboratories. Juran was perhaps less charismatic than Deming but extremely influential in the development of quality control and improvement. For reasons unknown he worked independently from Deming. Like Deming he visited Japan in the 1950's and 60's and taught his methods to senior Japanese management. Both received the Second Order of the Sacred Treasure award from Emperor Hirohito for the improvement to Japanese quality. It is suggested by both Juran and Deming that senior North American management was not interested in such methods at the time, believing that if it had any value then less senior employees would suffice in its deployment. Juran's methods can be seen to link closely to those used today by Six Sigma proponents (Pyzdek 2003). Six Sigma is a quality improvement philosophy and methodology that specifically sets the goal for quality as no more than 3.4 defective parts or mistakes per million opportunities (Pyzdek 2003).

Juran used the Pareto principle in Japan in the 1960's in terms of its application to quality improvement. His classic book "The Quality Control Handbook" first published in 1951 is still widely in use today (Juran 2000).

The Quality Trilogy, shown below in Table 2.1, was conceived by Juran by reflecting on the way businesses managed finance, i.e. financial planning, improvement and control. It was Juran's view that businesses should approach quality management with the same level of rigour and importance as that given to financial management.

Table 2.1 Juran's Quality Trilogy

Quality Planning	• Identify who are the customers. • Determine the needs of those customers. • Translate those needs into our language. • Develop a product that can respond to those needs. • Optimise the product features so as to meet our needs and customer needs.
Quality Improvement	• Develop a process which is able to produce the product. • Optimise the process.
Quality Control	• Prove that the process can produce the product under operating conditions with minimal inspection. • Transfer the process to Operations.

2.1.8 Training Within Industry (TWI)

The TWI Programme was born of industrial crisis, namely the need to produce arms with which the United States of America (USA) could defeat Japan during World War Two.

During the war effort in the USA, the TWI programme was widely used especially in shipbuilding. In the two years that followed the Battle of Midway, the Japanese managed to launch six new aircraft carriers versus seventeen in the USA (Graupp and Wrona 2006). This widespread productivity improvement methodology consisted of a three-pronged approach:

1. Job Instruction Training – this "train the trainer" part taught supervisors how to instruct employees.
2. Job Methods Training – How to improve job methods.
3. Job Relations Training – How to lead people so that problems are prevented.

At the end of the Second World War the USA shut down the TWI programme as it was viewed as no longer necessary. During the occupation of Japan, needing to help the Japanese improve their industrial output quickly, America looked again to the TWI programme to achieve this. This approach was adopted by many companies including Toyota (Graupp and Wrona 2006).

2.1.9 Taiichi Ohno and Shigeo Shingo

Toyota started out as Toyoda, originally a manufacturer of weaving looms. Sakichi Toyoda invented the first loom with a built-in device that would make it stop if the thread broke (Mistake-Proofing). This first mistake-proofing device appears to have spawned one of the most important cultural aspects of the Toyota Production System, namely to prevent mistakes happening in the first place and if a mistake is made to immediately stop the line and fix the problem rather than do rework later. His son Kiichiro founded the car manufacturing business, and attempted to emulate Ford's production system. However, customer requirement was different in Japan due to the need to produce low volume and high variety. The Ford system, which was based on high volume-low variety, would not work in Japan (Ohno 1988).

Taiichi Ohno is widely credited as being the "father" of the Toyota Production System. In the 1940's and early 1950's, Ohno was the assembly manager for Toyota and developed many improvements that eventually became the Toyota Production System. Toyota was verging on bankruptcy during much of this period and could not afford major investments in new equipment or massive inventories. In his book “The Toyota Production System,” Ohno (1988) describes Toyota’s objective for their production system at the time as trying to shorten the time between an order being placed to money in the bank. In order to shorten this time, Ohno identified seven kinds of process waste which if eliminated would improve operations.

These are:

1. Excessive Transport
2. Inventory
3. Worker Motion (Ergonomics)
4. Waiting or delay between value adding steps
5. Overproduction (Making more than the next process needs)
6. Over processing
7. Defects

Shigeo Shingo, a consultant to Toyota and hundreds of other companies, was a key collaborator with Taiichi Ohno. He introduced the concept of Single Minute Exchange of

Dies (SMED) which was a key enabler for small batch or single piece flow production as well as further developing the principle of mistake-proofing at source, which radically reduced defects and the need for mass or sampled inspection (Shingo 1985). Tools and techniques that emerged from the collaboration of Ohno and Shingo appear to simply reflect their desire to solve the problems that they witnessed. In fact it might be argued that creative problem solving was their greatest contribution. Shingo gives credit to Gilbreth for his 18 “Therbligs” (types of motion). Under unfavourable circumstances, and with little financial resources, they developed the Toyota Production System which is now acclaimed to be the exemplar of manufacturing and design efficiency (Ohno 1988). To put this in context and explain the extent of the success of this system Toyota makes more profit than the big three USA auto manufacturers put together, but employs less people than any one of them (Graupp and Wrona 2006). It is highly probable, given the evidence in the literature, that the other key innovators mentioned so far, also highly influenced the development of TPS (Ohno 1998).

2.1.10 The Toyota Production System

There is clear consensus in the literature that the Toyota Production System is the exemplar of lean production.

TPS is characterised by low inventory levels, high productivity and high quality when compared to other organisations carrying out similar work. Derived from the book “The Machine that Changed the World” (Womack, Jones and Roos 1990) the data portrayed in Table 2.2 below highlights how extraordinary Toyota’s, and other Japanese automotive manufacturers’ performance was in comparison to their European and North American counterparts in the 1980's.

In "Lean Thinking" (Womack and Jones 1996), an attempt is made to concisely describe both the philosophy and route map of lean as follows:

1. Understand *Value* from the Customer's viewpoint.
2. Understand the *Value Stream*. Every step in the process from raw material to finished product, typically individual activities within this value stream are then categorised as either Value adding, support activity or wasteful.
3. Create *Flow* by removing non-value activity from the Value Stream.
4. Enable *Pull* by making only what is needed by the next process when it is actually needed.
5. Seek *Perfection* by constantly repeating and refining the above process

Table 2.2 Benchmark data from The Machine That Changed the World
Source: Womack, Jones, and Roos 1990

Category	**Measure**	**Japan**	**USA**	**Europe**
Output	Productivity (hrs/vehicle)	17	25	36
	Quality (defects/100 vehicles)	60	82	97
Workforce	% of work force in teams	69	17	1
	Number of job classes	12	67	15
	Suggestions/employees	62	1	1
Layout	Space (sq.ft/vehicle/year)	6	8	8
	Repair area - % of assembly	4	13	14
	Inventories (days)	0.2	3	2

Stephen Spear (Spear 1999) attempts to describe the "DNA" of the Toyota Production System as follows:

- Four rules
    - All work shall be highly specified.
    - Every customer supplier connection must be direct (internal and external).
        - Unambiguous way to send requests and receive responses.
    - Pathway for every product and service simple and direct.
    - Any improvement made using scientific method with the aid of a teacher at the lowest possible level.
- Four questions (to be asked at the coal face) (to test for leanness?)
    - How do you do this work?
    - How do you know you are doing this work correctly?
    - How do you know that the outcome is free of defects?
    - What do you do if you have a problem?

It can be observed that there is a clear link between Spear's four rules and the TWI standardised work approach.

There also appears to be a resemblance between Deming's 14 points and another set of 14 points codified as "The Toyota Way" (Liker 2004). In "The Toyota Way", Jeffrey Liker sets out 14 principles of the Toyota Production System. Some of these principles are "action based", i.e. tangible things that a company must do and that would be visible to an outside observer. Other principles are of a more philosophical nature. In Table 2.3 below, a comparison is made between Deming's 14 points and those of Toyota. An attempt has been made to align those that are similar and identify *Toyota specific* characteristics (highlighted in yellow); these could be useful in understanding the difference between lean and other improvement philosophies such as Total Quality Management.

Table 2.3 Comparison of the Toyota Way 14 Points to Deming's 14 Points

Comparison of the Toyota Way 14 Points to Deming's 14 Points			
Point No.	Toyota	Point No.	Deming
1	Base your management decisions on a long-term philosophy, even at the expense of short term financial goals	1	Create constancy of purpose toward improvement of product and service, with the aim to become competitive and to stay in business, and to provide jobs.
2	Create continuous process flow to bring problems to the surface	3	Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place
3	Use the "Pull" system to avoid Overproduction		*Toyota Specific*
4	Level out the workload (*Heijunka*)		*Toyota Specific*
5	Build a culture of stopping to fix problems, to get quality right first time	8, 11, 12	Drive out fear, so that everyone may work effectively for the company. Remove barriers that rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality. Remove barriers that rob people in management and in engineering of their right to pride of workmanship.
6	Standardised Tasks are the foundation for continuous improvement and employee empowerment	6	Institute training on the job.
7	Use Visual Controls so no problems are hidden		*Toyota Specific*
8	Use only reliable, thoroughly tested technology that serves your people and processes		No direct correlation, although Deming was known for being sceptical of "Gadgets"
9	Grow leaders that thoroughly understand the work, live the philosophy and teach it to others	7	Institute leadership. The aim of supervision should be to help people and machines and gadgets do a better job. Supervision of management is in need of overhaul, as well as supervision of production workers.
10	Develop exceptional people and teams who follow your company's philosophy.	2 14	Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change. Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.
11	Respect your extended network of partners and suppliers by challenging them and helping them improve.	4	End the practice of awarding business on the basis of a price tag. Instead, minimize total cost. Move towards a single supplier for any one item, on a long-term relationship of loyalty and trust.
12	Go and see for yourself to thoroughly understand the situation (Genchi Genbutsu).		*Toyota Specific*
13	Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly (nemawashi).	9	Break down barriers between departments. People in research, design, sales, and production must work as a team, in order to foresee problems of production and usage that may be encountered with the product or service.
14	Become a learning organization through relentless reflection (hansei) and continuous improvement (kaizen).	13 5	Institute a vigorous program of education and self-improvement. Improve constantly and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.

It is well-known that the exemplar of lean is Toyota and the philosophy, characteristics, tools and techniques of TPS can be described. However, is it possible to produce an "operational" or testable definition of Lean? This is important for research purposes because, to date, no satisfactory definition of Lean exists, let alone a definition of lean construction (Dauber 2003; Green and May 2005; Pettersen 2009).

2.2 Operational Definitions

Operational definitions become necessary whenever cloudy language or specifications are present. For example, words including "more, less, thorough, better, longer, correct, high quality, lean" carry no communicable meaning for use in industry and are a cause of much angst and waste. Koskela (2000) is clear in his view that properly developed (defined) production theory is necessary to better enable success in the construction industry, and Koskela is critical of Womack and Jones' five lean principles in that the terms they use are *"imprecise and unsystematic"*.

2.2.1 What is an "Operational Definition"?

Shewhart invented Statistical Process Control (SPC), which revolutionised quality management. However, Shewhart regarded his work on operational definitions just as important as SPC (Shewhart 1939). Deming carried forward the work of Shewhart on this subject and both these men give credit to the philosopher C.S. Lewis for inspiring the concepts of operational definitions and also the Shewhart Cycle (Plan, Do, Study, Act.) which later became a key part (Theory of Knowledge) of Deming's "Profound Knowledge" system (Deming 1994).

In “Out of the Crisis” Deming (1986: 276) writes:

> *“There is nothing more important for transaction in business than use of operational Definitions… The only communicable meaning of any word, prescription, instruction, specification, measure, attribute, regulation, law, system, edict is the record of what happened on application of a specified operation or test… Adjectives like good, reliable, uniform, round, tired, safe, unsafe, unemployed, have no communicable meaning until they are expressed in operational terms of sampling, test, and criterion”.*

An operational definition puts communicable meaning into a concept. It is certainly the case that Lean Thinking and Lean Construction are concepts and there is a great deal of confusion in industry regarding these concepts.

According to Deming (1986), the formation of an operational definition is a three stage process where:

1. A specific test of a piece of material or an assembly;
2. A criterion (or criteria) for judgment;
3. Decision: yes or no, the object or the material (or concept) did or did not meet the criteria.

By way of example, the author visited a building site where a number of fire door installations had been condemned by the client’s inspector due to “unacceptable gaps” around them. Much argument took place about what was acceptable and what was not, and this caused delay and extra cost in addition to solving the original problem.

In order to establish an operational definition of "acceptable gap" for the installation of a fire rated door in its frame, the three steps discussed above need to be carried out thus:

1. Fabricate two gauges made of beech wood of the dimensions 2mm x 50mm x 100mm. and 4mm x 50mm x 100mm.

   Insert the 2mm gauge between the edge of the door and the frame and move it the full height of the door. Repeat on each side and the head.

   Repeat this process with the 4mm gauge.

2. Gap between door and frame to be minimum 2mm and maximum 4mm.

3. If the 2mm gauge can pass freely all the way around, and the 4mm gauge will not enter the gap at any point, the work is correct. If not, it is incorrect.

2.3 Towards A Definition Of Lean

This leads to two important questions: Is it possible to define lean in this way? How could its presence be tested?

In the available literature it is possible to find descriptions of the characteristics and tools of lean; however none of these provide a satisfactory operational definition. Perhaps one of the best attempts made is “Read a plant fast” by Goodson (2002) where a table of 20 lean characteristics is formed, (criteria) which can then be checked for their presence or absence by direct observation of the plant in focus, with the number out of 20 scored indicating the current degree of leanness. However some of the questions are still subjective, relying on the experience of the observer to make a judgment whether yes or no.

Another way of thinking about this problem might be to compare "lean" performance with normal performance. Based on the data in Table 2.2 on page 19 Lean performance could be said to be "exceptional" because the performance gaps are so great that it is not logical to suggest such improvement happened by accident or chance.

Continuous improvement will have certainly taken place in the USA, Europe and Japan during the period documented in “The Machine That Changed the World”. However, it is clear that Japan improved at a much faster rate, and this leads to a potential new research question that it may not be improvement itself that matters as much as the speed and constancy of improvement.

If this were true then applied lean thinking would exceed the expectations of companies that were unfamiliar with the concept if successfully applied for the first time, as it would enable speedier improvement. It could also continue to return positive results if applied constantly.

Therefore it may be possible to construct criteria that would describe the characteristics and behaviours of lean production and also in theory use a measure of performance that might describe “exceptional”.

2.3.1 Other Business Improvement Methodologies

It is clear, then, that lean is a production system synonymous with Toyota that is also capable of exhibiting exceptional performance. However, other production or business improvement methodologies do exist that might also lead to “exceptional” performance. For example, the Six Sigma programme in the 1980s at Motorola led to exceptional quality improvements that allowed Motorola to dominate the world market in mobile handsets for several years (Pyzdek 2003).

Many other approaches to business improvement can easily be found in the literature including Six Sigma, Lean Management, Lean Six Sigma, Agile Management, Business

Process Re-engineering, Total Quality Management, Just-In-Time, Kaizen, Hoshin Planning, Poka-Yoka, Design of Experiments, Theory of Constraints (TOC) and many others. However the key approaches that appear different enough to warrant a comparison include the Toyota Production System (TPS), Total Quality Management (TQM), Six Sigma, Theory of Constraints (TOC) and Business Process Re-engineering (BPR).

Whilst these Methodologies do appear sufficiently different to warrant comparison some still contain very similar sets of characteristics in terms of the tools they use or particular areas of focus. Therefore it may be useful to examine if any characteristic set is explicitly "Lean". This in turn may help to define Lean. An attempt to compare these key methodologies by the emphasis each places on the various characteristics; is shown in Table 2.4 below. The five methodologies are in the first row and the characteristics are in the first column. Where each methodology intersects with each characteristic, the level of emphasis is marked as high, medium and low.

The table represents the opinion of the author, who has been trained in the Toyota Production System, is a Six Sigma Blackbelt, a student of Juran, Deming and Goldratt, and a practising lean consultant with 13 years experience in this specialist field.

Table 2.4 Comparison of Business Improvement Methodologies. Key: H–High; M-Medium; L–Low; WIP – Work in Progress; SPC – Statistical Control Process; SMED – Single Minute Exchange of Dies; OEE – Overall Equipment Effectiveness

Characteristic					
	Toyota Production System	Total Quality Manage ment	Six Sigma	Theory Of Constraints	Business Process Re-engineering
Visual Management	H	L	L	M	L
SPC	M	H	H	M	L
Low WIP	H	L	L	H	L
Di-section of types of waste	H	L	L	M	L
Standardised work	H	M	M	M	M
Problem solving	H	H	H	H	H
SMED	H	L	L	H at Constraint.	L
Error-proofing	H	H	M	H at constraint	L
Empowered teams	H	H	M	M	L
Continuous improvement	H	H	H	H	L
Stop to fix problems	H	L	L	L	L
OEE	M	M	M	H at constraint	L
Workplace organisation	H	L	L	L	L
Design of experiments	L	M	H	L	L
Voice of customer	H	H	H	M	H
Supplier integration	H	M	L	M	M
Focus on quality	H	H	H	H	M
Focus on complexity	H	H	M	M	H
Focus on speed	H	M	L	H	M
Systems thinking	H	M	L	H	M

2.4 Discussion

Table 2.4 is very much an overview and represents the opinion of the author based on previous research and experience. In individual case studies or examples these characteristics might change significantly. Taken as a whole and from the literature available, however, they may provide a further step in defining lean (Henderson 2003; Goldratt 1984; Juran 2000; Pyzdek 2003; Womack and Jones 1996).

The first thing noticed is that TPS has a high focus in all but two of the characteristics. Further, all methodologies have a high focus on problem solving but at different levels within the organisation, i.e. Toyota's focus is at "the lowest possible level" but BPR would be at a much higher level (Spear and Bowen 1999).

It would appear that Theory of Constraints is the only system apart from TPS to have a high focus on low levels of Work-in-Progress (Any task, product or part that has been started but is not finished). TOC also uses many of the other techniques but focuses them at the constraint first. Single Minute Exchange of Dies could be discounted because its purpose is to minimise WIP, so the focus is the same.

Workplace organisation and visual management could be classed as one category as they are so similar; with visual management techniques (displays and controls) being used extensively to enhance the organisation of the workplace by making it obvious to anyone working there to know what to do and what not to do. For the purpose of this research, it is here renamed "visual workplace". This is a defining characteristic.

Di-section of types of waste is an Ohno invention (Ohno 1988), and represents a particular form of problem solving, or rather problem identification. However the key observable characteristics that result from di-section of waste are low WIP and the visual workplace.

The most obvious characteristics that differentiate lean from other methodologies are low levels of WIP, the Visual workplace, Stopping to fix Problems and Problem Solving at first line supervisor level. In his book "The Toyota Production System" Ohno (1988) stressed that the techniques developed were as a result of trying to solve specific problems and that all he was really trying to do was shorten the lead time between order placed and money in bank. Therefore the characteristics of The Toyota Production System were developed as a response to a much broader philosophy and the specific needs/problems encountered by Toyota. In other words, to try to completely replicate this production system in a different setting would not necessarily achieve the same results. It is felt however that the characteristics of low WIP, the Visual Workplace and Problem Solving are universally useful to any production system, and if combined with hard metrics of performance might usefully serve as a good starting point for the creation of a definition of lean production.

2.5 What Is Lean Construction?

A significant body of literature has been developed by members of the International Group for Lean Construction (IGLC) formed in 1993, and the Lean Construction Institute (LCI). The majority of the literature is concerned with new build construction projects using sub-contract labour and how they are managed (Abdelhamid 2007; Ballard 2000a; Howell 2004; Koskela 2000; Lichtig 2005; Mastroianni and Abdelhamid 2003; Salem et al. 2005). It appears pre-occupied with the sub-contract nature of the industry and how to best manage this. In addition there is very little said about the maintenance or facilities management sector and little in the way of change management theory relative to lean construction, or how lean thinking applies directly to Small and Medium-sized Enterprises (SME's) (European definition of Companies with less than 250 employees). The available construction statistics for UK interestingly do not align with the European company size definitions, but they do show that over 99 per cent of the total number of construction companies in the UK has less than 60 employees, and that this accounts for approximately 42 per cent of spend. So 58 per cent of spend occurs in less than 1 per cent of the number of relevant companies in the UK (Department for Business, Enterprise and Regulatory Reform (BERR) 2007). A brief overview of some key contributions follows below.

Koskela (1992), a founding member of the IGLC, discusses the potential application to construction of "the new philosophy" of lean production and concludes that construction should adopt this philosophy. He also makes the distinction between a conversion process and a flow process where a conversion process is concerned with only value adding activities whereas a flow process is also concerned with waste. (See value stream and seven wastes above in 2.1.10 and 2.1.9, respectively). Koskela also makes a key contribution by observing that construction planning takes no account of process waste and only plans the conversion activities. Ballard and Howell (1994) extend this flow process and begin to quantify the production losses associated with the failure of planned activities to complete on time. In Ballard's (2000a) dissertation "The Last Planner System", he measures planned activities daily versus complete activities as stated by works foremen. The average performance under study found that only 54 per cent of planned activities were completed when they were supposed to. This was due mainly to the failure of all the necessary process inputs to be in place prior to the commencement of the work.

Ballard suggests a change in thinking from planning what should be done to what can be done instead, and to put in place robust planning/checking methods to make sure that all process inputs are in place before the work is executed. In other words, trying to stick to a main contractor's programme, where a conversion process is “pushed” into production, causes day-to-day failure and production losses induced by variability in the actual process flows. Conversely, if short term (weekly) building activities can be “pulled” only from a list of tasks that have been properly made ready to start with all inputs properly in place, process flow and therefore productivity will improve. A potential flaw appears here at first in that there may be no guarantee that planning what can be done as opposed to what should be done will deliver against the master programme. However, in terms of productivity it was estimated that improving the planned activities complete indicator from 50 per cent to 70 per cent resulted in a 30 per cent productivity increase (Ballard 2000a). If productivity is increased by 30 per cent it should follow that the overall programme is more likely to succeed under this view of construction planning. More practical guidance on short term planning is provided by Horner and Duff (2001) where the impact of onsite delays are quantified, together with useful advice on a variety of productivity improvement techniques.

Koskela (2000) goes on to develop his Transformation-Flow-Value (TFV) theory in his thesis. Here he compares different production philosophies and separates them into the above three categories. He suggests that Lean is mainly concerned with the "Flow" theory of production and provides a useful critique of the work of Womack and Jones (1996). Koskela takes the view that the five lean principles described by Womack and Jones are “slogans” and fail to provide a proper theory of production. He concludes that all three theories of production are necessary simultaneously to succeed in the application of Lean Construction, and that this new TFV theory of production will work effectively to improve construction.

It can be observed that in construction the resources, i.e. people, materials and machines, move around the product (the building), as opposed to manufacturing where the opposite is true. Further, construction often deals with prototypes rather than repeatable products and therefore construction is by this very nature different to manufacturing and so needs a new theory of production. Koskela identified an "eighth" waste in construction as being "the waste of making do" meaning repeatedly attempting to start work before all process inputs are in place (Koskela 2004). One aspect of the Last Planner System is a direct focus on reducing this waste of making do by utilising process input checklists to ensure tasks are really ready to start.

It may be of interest to note that the Kawasaki Production System, reported to be an almost exact copy of TPS (Smith 2007), is used to build ships within their heavy industry division, where the resources must flow as in a construction site and products are prototypes. Other examples of the successful application of lean thinking to shipbuilding can be found in the wartime work of TWI (Graupp and Wrona 2006) and also in a “A Guide to Lean Shipbuilding” (Liker and Lamb 2000). Ship building also requires early procurement and design to succeed. For example, imagine trying to fit the engines and plant after constructing the shell. Clearly these must be built-in, deck by deck, or volumetrically, space by space. There are very clear similarities between shipbuilding and new build construction projects. It could be argued that the process is so similar that production systems between these two sectors would be directly transferable. If this is true, and the predominant construction research in lean thinking is looking for new theories of production, then it raises the question of why the industry is not adopting existing proven methodologies to enhance performance. This was observed by Stevens at the 2014 IGLC. Stevens (2014) also states that a lack of a suitable definition is a barrier, but that real proof that the application of Lean Construction improves profits and a method of measuring this would help uptake in the for profit private sector.

2.6 Towards A Definition Of Lean Construction

Rybkowski, Abdelhamid and Forbes (2013) offer a useful discussion on the merits or otherwise of whether Lean construction should be defined at all, and if in fact this would help. However, although no real conclusions are drawn in answer to this question, attempts are made in providing graphical definitions in the form of sketches on cocktail napkins. Again, if Shewhart's methodology is followed then these would not suffice.

There are, consistent with the offered definitions of lean production, many varied opinions with regard to lean construction, ranging from "lean construction is a multifaceted concept that defies universal definition" (Green and May 2005: 1) and "there is no universal accepted, explicit definition of lean construction" (Dauber 2003: 29), to Koskelas observation that the founders of the IGLC began referring to lean construction in 1993 as a mode and practice of construction inspired by the Toyota Production System (TPS) (Koskela 2004a).

It would certainly appear from the literature that many recent attempts at Lean Construction have been inspired by TPS, so the IGLC founder's suggestion is preferred here. However, it still does not meet Shewhart's requirement in terms of a definition, i.e. if a construction project was observed, how would a decision be taken to record the level of "leanness" of the project?

It would appear, as is the case of Kawasaki in shipbuilding, that lean production is readily translatable to construction. This is evidenced by many successful applications worldwide. These applications vary from applying "The Last Planner System", to fuller lean projects which use many of the tools and techniques of TPS such as Andon boards, Kanban cards, 5S workplace organisation and visual management techniques (Pereira 1998).

If an existing theory of production that is obviously superior can work in construction, this leads to the obvious question: "what is stopping its widespread adoption?"

2.6.1 Peculiarities of Construction

Ballard & Howell (1998) seek to understand construction as a form of production and conduct a comparison of production types. They identify several different kinds of manufacturing, and point out that construction most closely fits “fixed position” manufacturing which is used to build aircraft and ships. They also observe that little has been written about this type of production.

They identify two characteristics of constructions objects that when taken together could provide an explanation of the uniqueness of construction when compared to manufacturing modes of production. These are (1) construction belongs to the “fixed position manufacturing” category, where assemblies become too large to move through assembly stations and so the assembly stations themselves must move, and (2) is “rooted in place”. The rooted in place characteristic is observed to lead in turn to two types of conditions that pertain to construction. These are increased uncertainty caused by local conditions such as ground conditions or local regulations and also that the building must possess value for a customer who is local to it. They note that construction customers are often intimately involved with the process, attending sites as buildings progress.

Another difference discussed is a lack of supplier integration in construction and it is observed that as a general rule construction customers are not able to exert as much leverage on their suppliers as their manufacturing counterparts. Finally, it is suggested that construction is perhaps closer to a new product development process and is essentially a design process, but one in which the facilities designed are “rooted in place”.

Koskela (2000) reviews and discusses the peculiarities of construction and provides a useful summary of prior research. He records the key peculiarities as one-of-a-kind production, site production and temporary organization. He also discusses managerial practice and observes that research has been unable to produce an empirically validated, comprehensive theory of construction. He also concludes that managerial and organizational development has been different between the construction and manufacturing sectors and this difference, whilst still puzzling, is a key cause of lack of performance within the construction sector. Koskela hypothesises that these three peculiarities are a barrier to advancement in construction and also that it is necessary to reduce or mitigate their impacts in order to reduce waste and value loss. In other words, they are taken as key barriers to the implementation of lean construction. Several case studies are examined to gauge efforts to mitigate or eliminate these barriers and it is concluded that the hypothesis that these are a prime cause of waste in construction should be accepted. Within the same discussion Koskela also considers industrialisation of construction, now more commonly known as off-site production. He points out that whilst this is an attempt to mitigate or eliminate the peculiarities of site–production the track record of success is not good and indeed can actually lead to more waste rather than less if improperly managed.

Dauber (2003) discusses similar differences when comparing construction with manufacturing but in the context of tailoring lean to construction operations and focuses on the fixed position nature of production and the effect this has on resource management. He observes that this is a key constraint as it is not always possible to deploy the optimum resources due to the physical conditions of the work.

Vrijhoef & Koskela (2005) revisit the three peculiarities of construction and whilst they acknowledge that construction operations tend to improve when these are reduced or mitigated, they are also clear that these peculiarities do not automatically equal problems or waste, contradicting the view implied in earlier papers. They also bring useful balance to the discussion by observing that often extra investment is needed in order to eliminate these peculiarities and that the cost benefit trade-off should be considered. In addition, they take a very broad view of the construction process in the context of whole life value of an asset and imply that it may be acceptable to tolerate more waste if this results in higher value.

These papers mainly focus on physical attributes of production but do not fully consider these differences in the context of the constructions sector's motivation to improve.

2.6.2 Discussion

There is awareness that Lean Production is highly effective and that it is possible to apply its concepts, tools and philosophies to construction activities. However there still remains little overall adoption by the construction sector.

It is considered here that the combination of Ballard & Howells' two key criteria of fixed position manufacturing and rooted in place are sufficiently different to Koskelas' site production to warrant keeping them as separate concepts, not because of any production theory but because of the potential motivational effects they might have.

It is known that a direct translation of lean production to shipbuilding is possible. It can also be observed that shipbuilding contains the following similarities with construction: Fixed position and one-of-a-kind production. Key differences are that shipbuilding will likely not fit the temporary organisation category, and obviously ships are not rooted in place and once complete can be moved.

In the context of the deployment of lean thinking within the construction sector, of the key differences noted above, it is perhaps “rooted in place” that is most significant. This is because the rooted-in-place or local nature of projects can influence the basic motivation to improve. For example, if a company was competing in a truly global economy where items can be made and shipped easily then only the most efficient will survive and could not possibly compete with “lean” companies unless they also adopted similar systems.

This is not the case for most of the construction sector where buildings are put together *in situ* and competition is primarily on a regional or national basis rather than an international one. In the UK, Swedish and Dutch companies like Skanska and BAM have a good foothold. However, they still use mostly local supply chains and face the same problems as domestic competition. Whilst no real data is available at present there is nothing to suggest that there are any significant performance gaps between major contractors that operate in the UK in the same way that these gaps are, or more correctly were, present in the manufacturing sector. It is surmised that although multi-national companies are present; because of the “rooted in place” factor of buildings, the nature of competition is still actually regional and not global, and this means that a key motivational ingredient is missing.

If these construction peculiarities are now considered from the viewpoint of the work toward a definition of lean production in 2.4 above, it is necessary to ask whether they might form barriers that would make impossible the deployment of the key characteristics of lean production noted. However, there is evidence to suggest that it is possible to reduce WIP, employ the Visual Workplace and encourage Problem Solving within a construction environment, despite these peculiarities. (Ward and McElwee 2007; Pereira 1998; Ballard & Howell 1997)

So it follows that the characteristics of low WIP, the Visual Workplace and Problem Solving are universally useful to any production system, (including construction) and if combined with hard metrics of performance might usefully serve as a definition of lean construction.

Therefore, it may be the case that the most significant barrier to the uptake of Lean Construction does not lie in any techniques, philosophy or characteristics but in the construction industry’s ability or willingness to adopt the new philosophy.

2.7 Intervention Versus Transformation

Much of the key literature on lean production discusses lean in a transformational context with intense efforts to improve being sustained over several years, indeed sometimes decades in the case of Toyota and others and showing significant performance results. These “Transformations” however are made up of many smaller “Interventions”.

So far in the construction sector it is not easy to find any real evidence of company transformations along the lines reported in the automotive sector although it is the writer’s opinion that it is possible that they may begin to emerge by 2020. Conversely there are many examples of project based “interventions”. The purpose of this research is to identify factors that affect the success or otherwise of efforts to embed lean thinking within construction organisations. Given the lack of available data surrounding construction company Lean Transformations, it is suggested here that a distinction must be made between "Intervention" and "Transformation" in the context of lean thinking, in order to enable more quantifiable and accurate research.

For the purpose of this study an "Intervention" is described as a small-scale rapid improvement project, focussed on local operations, or one project or process in focus, and typically consisting of between 5 and 15 days facilitations by an internal or external change agent. In contrast, a "Transformation" can be described as a long-term holistic effort to re-organise a whole company that results in a sustained level of enhanced performance. Such an effort might need significant resources and typically take five or more years.

The timescales involved in designing, testing and measuring the success or otherwise of transformation for the purposes of this research would be extremely difficult to achieve within the available resources. In order to achieve greater focus, the intention here is to concentrate on "intervention" rather than "transformation". It is suggested however that as transformations consist of a series of interventions the critical success factors would be similar and so the output of the research project would be useful to both circumstances.

2.8 Critical Factors For Lean Construction Interventions

Based on the earlier observation that an existing superior theory of production; namely lean production, should be directly transferable to construction, it would be useful to examine under what circumstances lean construction intervention might be effective, i.e. lead to successful implementation.

There exists very little literature on this subject directly related to construction. However, there is substantial literature available regarding the manufacturing sector and in particular Total Quality Management (TQM) programmes and general business improvement initiatives. Whilst TQM and other methods may be viewed as different to Lean it is suggested that implementation would face similar barriers and therefore many of the critical success factors may also apply. The next part of this research examines the literature and common themes in terms of identifiable success factors are summarised.

2.8.1 Construction Specific Literature

Thorough searches for construction specific literature were conducted using a variety of suitable search terms between 2009 and 2013. During the final stages of this thesis a final check was carried out using Scopus in March 2015 using the search term "Critical Success factors for Lean Construction". This returned no results.

Holding possibly the largest repository of Lean Construction related papers, the International Group for Lean Construction - IGLC website now has an effective search engine. Again, using the term "Critical Success Factors" revealed five papers, four of which appear relevant.

In "Benchmarking - A Tool for Lean Construction", Marosszeky and Karim (1997) discuss the concept of benchmarking at length and its effect on the improvement of other industry sectors. They conclude that a version should be formed appropriate for construction and that this would be critical for success. This discussion is really based on the issue of widespread uptake within the sector, although it could be the case that knowledge that a competitor is performing at a higher level might trigger a sense of crisis.

In "Performance Improvement Programs and Lean Construction" (Mitropoulos and Howell 2001), three key factors for successful operational performance improvement programmes are identified:

1) Time Spent on Improvement – It is fairly obvious that the more time spent on improvement efforts the more likely they are to succeed. However, Mitropoulos and

Howell also make the link here with management commitment, i.e. management allowing their people the time to spend on improvement.

2) Improvement Skills and Mechanisms – This could be translated into a need for training or, at the very least, self study for staff.

3) Improvement Perspective and Goals – two forms of goal setting are discussed: result and process focused. It is stated that both are needed but at different levels, i.e. result at the strategic level and process at the operational level.

They also develop a useful model which depicts the interrelation or systemic nature of the improvement process, and identifies further causal or sub-factors that may influence the three key factors discussed above in either a positive or negative way depicted by + or – and reproduced in Figure 2.1 below.

They conclude that in construction the third key factor appears particularly important and explains the difference between "results focused" and "process focussed" using the following Table 2.5 to compare (Mitropoulos and Howell 2001:8). This paper is particularly relevant to the research project.

In "An Examination of the Barriers to Last Planner Implementation" Brady, Tzzortopoulos and Rooke (2011) examine the applications of the Last Planner System (LPS), but do not consider any other approach to Lean Construction. Three critical factors are identified as:

- Training in advance of attempted implementation.
- The use of Visual Management to aid communication.
- Adequate Preparation.

Visual Management as discussed earlier is a core defining lean characteristic. Its use is virtually always of benefit in any process improvement situation. Further, it is an intrinsic part of a lean approach and not a critical success factor for lean.

This point about “adequate preparation” seems confusing and mentions getting buy-in, agreeing roles and responsibilities and other points that could also fall broadly under the heading of training.

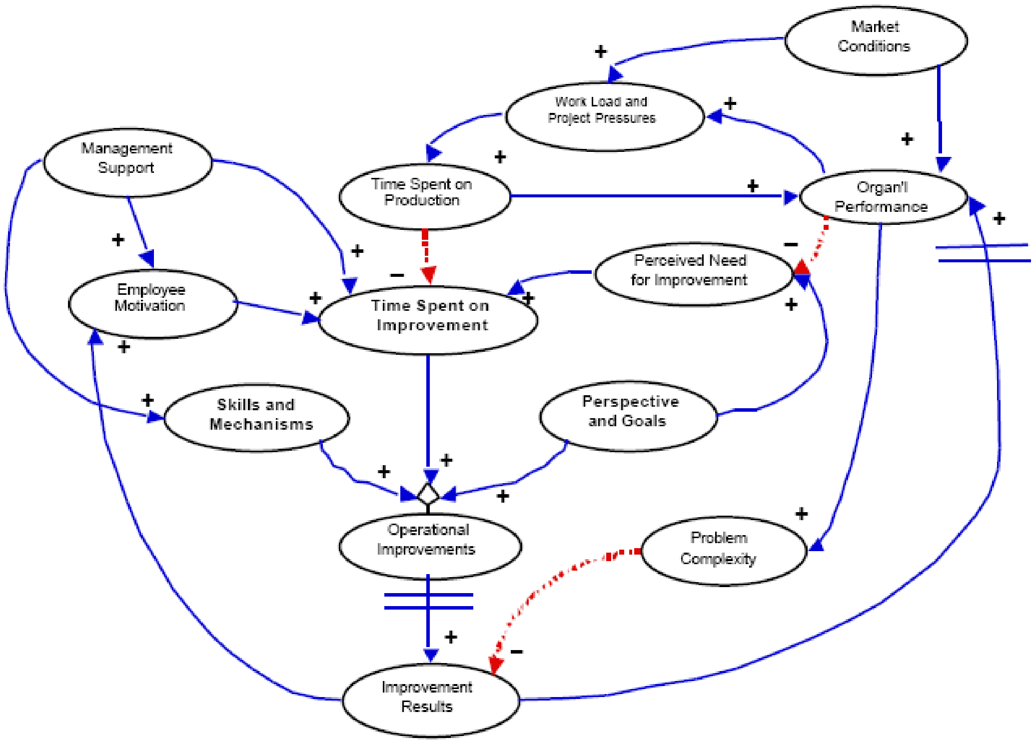

Figure 2.1 Model of performance improvement process
Source: Mitropoulos & Howell 2001

Mitropoulos and Howell (2001:3) explain that *“An arrow between factors means that factor X affects factor Y. A positive sign indicates that if factor X increases, then factor Y also increases. A negative sign indicates that if factor X increases, then factor Y decreases. A double line indicates a time lag. When more than one arrow converges to a diamond, then ALL of the conditions need to be present for the resulting factor to occur. For example, (1) “Time Spent on Improvement”, (2) “Skills and Mechanisms”, and (3) “Perspective and Goals” must ALL be present for effective “Operational Improvements” to occur.”*

In "Last Planner System: Experiences from Pilot Implementation in the Middle East" by AlSehaimi, Tzzortopoulos and Koskela (2009), two case study construction projects are examined using a variety of research methods. This work identifies the Critical Success Factors as top management support, commitment to promises, involvement of all stakeholders and communication and coordination between parties. It is observed that Alsehaimi and colleagues blame the Arabian culture and attitudes toward time keeping. This a peculiarity of this research paper and particularly relates to the "commitment to promises" factor.

Table 2.5 Approaches to quality improvement
Source: Mitropoulos & Howell 2001

	Result focused	Process focused
Goal	Zero Punchlist at time of completion	Eliminate defects
Causes	• Defects not identified earlier • Incorrectly installed work • Damaged work	• Defects not prevented • Incorrectly installed work • Damaged work
Emphasis on:	• Subcontractors Responsibility • Inspections	• Work Process design
Improvement initiatives	• Do more inspections earlier • Causal analysis limited to identifying who failed and must repair work. • Train employees to identify defects • Discuss with subs the importance of zero punchlist, motivate, reward subs • Include clauses for work protection • Backcharge for damaging other trades work	• Assure processes are under control. • Root cause analysis–5 "why's" • Understand level of quality is needed/wanted by "customer" • Effectively communicate quality requirements • Sequence work to reduce schedule pressures and damages • Better manage trades interdependencies • Change the work method, process, and tools.

2.9 Critical Success Factors From The Non–Construction Literature

In the book "Lean Thinking" it is stated that in order to succeed in lean a crisis must be present and that if there is no crisis, one must be created. Further, all efforts should be focused on the end user (Womack and Jones 1996).

Bateman (2001) studied “masterclass” style interventions using lean improvement activity carried out by the SMMT Industry forum in the manufacturing sector. This paper is particularly relevant as the Industry Forum Model was adopted by the Construction sector in the UK under the Construction Lean Improvement Programme, managed by the Building Research Establishment from 2003 to 2008 (DTI 2006). This was a government-funded programme specifically aimed at introducing lean thinking to the UK construction sector.

Bateman’s prime research concern was not the immediate success of the interventions but whether or not the improvements were sustained. However, it is highly likely that the initial success would be closely linked to the sustainability of the improvements. Bateman (2001:10) also offers a definition of “continuous improvement” as “the team uses the tools and techniques learned during the master class programme to solve new issues and to improve further the performance of the model area.”

This study classified five types of teams, A to E, in terms of achievement of sustainability of improvement: "A" teams not only sustained the gains made during the initial intervention but continued to improve without further aid. "B" teams managed only to sustain the gains made during the intervention and all the rest of the teams (“C”, “D” and “E”) slid backwards to varying degrees in terms of performance. The differentiating factors with the “A” teams were that the teams:

1. Maintained the new procedure;

2. Closed out technical issues;

3. Continued to improve after the intervention.

The enablers of “A” teams were:

- Consistency and buy-in - Changes to operating methods should be formally introduced to all cell members.

- Strategic Direction – the cell (team) should have a strategy or long term goals.

- Factory level support and focus – There should be somebody coordinating Process Improvement (PI) activities across the factory with the full support of senior management.

- Senior Managers should be involved in improvement activities.

- Senior managers should stay focused on PI activities and should be expected to report progress together with usual business objectives.

Bateman does not state these inputs in any order of preference or degree of criticality. The reader must assume that all enablers are equally important. Interestingly, a list of enablers for “B” teams was also produced, with “B” teams’ performance being regarded as generally good with the original improvements achieved during intervention having been sustained. The only common “enabler” between “A” teams and “B” teams was that managers should stay focused on continuous improvement.

Beer, Russell and Spector (1990) state that change programmes (interventions) must be *task focussed* (alignment of tasks) rather than generally trying to change attitudes by training and the development of vision and values. They go on to name three factors essential to success: coordinated *teamwork*, *commitment* and new *competencies*. They also state that all three must be present.

It would appear that the co-ordinated teamwork referred to actually means cross-functional teams from a systems thinking point of view and that the key is *behavioural change* driven by a system-wide approach (Zokaei et al. 2010). Also, the task-focused approach if linked with new competencies would make a good case for a “learning by doing” approach which was taught by the SMMT Industry Forum (DTI 2006) and this is consistent with the author’s own experience.

Beer (2003) examines Total Quality Management programmes and exposes a gap between management rhetoric and the reality at the coal face when change programmes are attempted. He suggests that unless these are dealt with honestly by the organisation as a whole by way of an "organisation-wide conversation", change programmes are likely to fail. He blames management for failed change programmes but in particular, unit level management. Framing the problem as "It’s not the seed, it’s the soil that matters", he goes on to clarify "fertile soil" as:

1. The capacity of the senior team at the corporate and unit level to develop commitment to TQM through an effective dialogue about why the company should adopt TQM and agreement about what must be done to implement it.

2. The capacity of the senior team to follow up their initial commitment with changes in organisational arrangements (a cross-functional team-based organisation) and behaviour (their own and that of sub-unit leaders) needed to support their TQM intentions.

3. The capacity of the senior team to create an honest organisation-wide conversation about the effectiveness of TQM implementation from which they can learn about the quality of their management and leadership in moving change along (Failure to address the "silent barriers").

4. Managerial capabilities must exist in all sub-units of the corporation for successful TQM transformation to take place.

Beer (2003) makes a clear distinction between types or levels of leadership and the influence these have on success, concluding that “Unit Level” leadership is the key. In a construction setting this would equate to a project manager or possibly a regional director.

Beer goes on to illustrate this with case study material. Of particular note is the UK grocer ASDA, who instigated a change programme based on the learning gained from three experimental stores. After the initial rollout failed, they conducted a "driving test" of their store managers, which assessed whether the store managers’ skills in leading the change process were aligned with the intended changes. If the manager did not meet the requirements they were given training. If they still did not then meet requirements they were dismissed. It is stated that Asda replaced 60% of their store managers in the period in question (6 years), and that after this the company was sold to Walmart for 8 times its pre-transformation value.

This aligns with Collins' (2001) research in his book “Good to Great” where the first thing that the successful companies did was actually to focus on getting the "right" people on board. It also raises the question, or perhaps begins a discussion, of how to get “buy-in” which has already been mentioned as a factor (Bateman 2001; Brady, Tzzortopoulos and Rooke 2011)

Beer (2003) recommends a five-step process to address the quality of management to allow a successful transformation programme. He calls this Organisational Fitness Profiling.

1. Insist that the leadership teams discuss the appropriateness of TQM to their sub-unit's business model and problems.
2. Insist that the leadership team engages a task force of its best managers as partners in a data collection and dialogue process about barriers to TQM implementation.

3. Insist that the data collection and discussion process allows important, often threatening issues to be raised and "publicly" discussed.

4. Insist that the senior team conducts a diagnosis of organisational and management barriers to TQM and develops a comprehensive action plan for change.

5. Insist that change plans be stress-tested by the senior team with those who must implement them to determine their validity and the organisation's willingness and capacity to implement them.

The steps above are clearly concerned with transformation and not simply intervention, although the concept of "lining up one's ducks" in terms of "buy-in" before beginning may well be critical.

Buchanan et al. (2005) conducted an extensive literature review of sustaining organisational change. They highlight that much work had been done to identify critical success factors for business improvement, but point to a gap in knowledge regarding the critical success factors of sustaining the gains. An offered definition of sustainability comes from the NHS Modernisation Agency (2002: 12) and begins:

> *"Sustainability is when new ways of working and improved outcomes become the norm. Not only have the process and outcome changed, but thinking and attitudes behind them are fundamentally altered and the systems surrounding them are transformed in support."*

Table 2.6 (see below) summaries Buchanan's factors affecting the sustainability of change. Having identified the above from the literature as critical success factors, Buchanan goes on to point out a gap in knowledge concerning the weightings for these. It is observed that this list could also apply to those factors required to achieve the initial change as well as sustainable change.

Table 2.6. Buchanan's factors for sustainability of change

Category	Outline Definition
Substantial	Perceived centrality, scale, fit with organisation
Individual	Commitment, competencies, emotions, expectations
Managerial	Style, approach, preferences, behaviours
Financial	Contribution, balance of costs and benefits
Leadership	Setting vision, values, purpose, goals, challenges
Organisational	Policies, mechanisms, procedures, systems, structures
Cultural	Shared beliefs, perceptions, norms, values, priorities
Political	Stakeholder and coalition power and influence
Processual	Implementation methods, project management structures
Contextual	External conditions, stability, threats, wider social norms
Temporal	Timing, pacing, flow of events

Buchannan's factors echo many of those already discovered, e.g. perceived centrality, scale, fit with organisation, and these factors link closely with Beer's need to hold an organisation wide conversation about the appropriateness of the improvement efforts. Next, individual competencies, emotions, commitment etc. link clearly with the concepts of training and getting buy-in. In fact, all of the factors can be linked with others already found and described earlier.

An attempt was made to establish the relative importance of TQM elements in actually achieving change (Samson and Terziovski 1999). These elements broadly follow the structure of the European Foundation for Quality Management (EFQM) business excellence model and are listed as following:

- Leadership.
- Management of people.
- Customer focus.
- Use of information and analysis.
- Process improvement.
- Strategic and quality planning.

The study found that the first three items had significantly more impact on performance than the second three. However, the sample of companies used for the study were randomly picked from across industry and not focused on leaders in TQM or Lean. So whilst it may be found that the first three items are more significant generally across industry it may not be the case for the top performing companies or award winners. Also, was it the case that "use of information and analysis" enabled and empowered "leadership" and "management of people"? What is the difference between “Management of People” and “Leadership”?

2.10 Summary Of Critical Success Factors and Literature Review

There appears to be an almost endless list of factors that may affect success. The list in Table 2.7 below is not exhaustive, but represents some of the possible key ingredients for a successful Lean Construction Intervention based on a review of the literature.

A history of the development of lean thinking has been described in this chapter and some progress has been made toward a definition of lean. However, in a construction

Table 2.7 Summary of critical success factors found in literature review

	Critical Success Factor	**Source**
1	There must be a crisis	Womack & Jones 1996, Marosszeky & Karim 1997
2	There must be buy-in from the improvement team	Bateman 2001, Brady et al. 2001)
3	There must be buy-in from Senior Management	Bateman 2001, Mitropoulos & Howell 2001, AlSehaimi et al. 2009
4	Efforts must be process focussed not result focussed	Mitropoulos & Howell 2001
5	Improvement goals must be set	Bateman 2001
6	The focus must be on the end user	Womack & Jones 1996
7	The intervention must involve all stakeholders	AlSehaimi et al. 2009
8	Management must be capable	Beer 2003
9	Senior Management must be directly involved	Bateman 2001
10	Management must stay focussed on the efforts	Bateman 2001
11	Appropriate training is critical for success	Mitropoulos & Howell 2001, Brady et al. 2011
12	It must be a learning by doing approach (ask oriented)	Beer 1990
13	Actions must be closed by team	Bateman 2001
14	People must be allowed enough time to spend on improvements	Mitropoulos & Howell 2001
15	High level of communication between suppliers is key	AlSehaimi et al. 2009
16	Must overcome silo thinking to succeed	Beer 1990, Zokaei et al. 2010
17	The Intervention must be linked to a long term strategy	Liker 2004, Deming 1986 & Bateman 2001
18	There must be an organisation wide conversation about the proposed effort	Beer 2003
19	An assessment of barriers to change must be carried out and an action plan formed	Beer 2003

setting it is felt that obtaining the necessary data to test this definition would not be possible within the scope and limitations of this research. Further, the available construction literature does not appear to offer any real answers in terms of what will help the successful deployment of lean thinking in construction, apart from the suggestion that Benchmarking could help (Marosszeky and Karim 1997), although there is good practical guidance available on lean thinking applied to construction and its links to productivity (Horner and Duff 2001).

Whilst there are clues in the literature from other sectors regarding critical success factors, these have not been established in construction. In Jurans' (2000: 217) words:

> "*Many of the strategies adopted by the successful companies are without precedent in industrial history. As such, they must be regarded as experimental. They did achieve results for the role model companies, but they have yet to demonstrate that the efforts to make such adaptations will generate new inventions, new experiments, and new lessons learned. There is no end in sight*."

Therefore, there appears to be a gap in knowledge in terms of a definition of lean construction and also an opportunity to test which success factors are most important for the successful application of Lean Construction.

CHAPTER 3 - METHODOLOGY

3.1 Methods and Materials

A review of the literature identified a number of critical success factors for the adoption of lean thinking. Some were obtained directly from construction related literature but the majority were from other industry sectors. Three key considerations led to the overall strategy for the research:

- The lack of a satisfactory definition of lean or lean construction.
- The lack of construction specific literature relevant to the research question - "what are the critical success factors for lean construction intervention".
- The unique resources available to the researcher.

Considering the list of CSFs found in the literature in Section 2.10, it was desirable to devise a suitable method or methods to test for the presence or absence of these factors in real life situations. A number of options were considered. The use of existing case study material was rejected because this might not necessarily include information about the presence of relevant CSFs. The methodical construction of lean interventions where one by one the CSFs could be included or omitted would be not only impractical due to cost and time constraints, but also possibly unethical if it deliberately caused failure in real life situations. Given the conceptual nature of the topic in focus and lack of clear definitions, it was also felt that the perceptions of the people involved were what mattered most. For example, when considering CSF 1 (There must be a crisis), one person's "crisis" could equally mean just a normal situation to another, so a reasonable way of deciding presence or absence of crisis would need to be determined.

The choice of research instrument therefore rested between a questionnaire and interviews. Whilst questionnaires might have increased the reach of the research, in a subject area as complex as this, it was decided that interviews were necessary in order to check the understanding of the respondents and to enrich their responses. Thus, the main approach toward data collection adopted here was to interview a sample of construction professionals and supervisors known to have taken part personally in efforts to apply lean construction, and attempt to discover their perceptions and opinions about which success factors are critical.

The research benefitted from the researcher's full time job as managing director of a management consultancy specialising in lean construction, and this was a key driver for the research method chosen. As a result, direct one-to-one access to a wide range of construction professionals who had been involved in efforts to apply lean thinking was uniquely available to the researcher, and it was felt that this asset was the most important consideration of all.

Not all questioning methods were chosen at the outset but they evolved and were evaluated during the research itself in response to what was learned at each stage and the data that emerged.

The research as a whole ended up using several methods, including semi-structured and structured interviews, as well as appropriate statistical tests to examine data from the main study.

3.1.1 Logic used to identify criticality

Critical factors were identified from the literature by gauging the importance placed on the factors by the authors concerned, for example if the authors used terms such as "critical, vital, absolutely necessary for success, or if an actual list of key attributes for success was listed as in Bateman (2001), these were carried forward. During the pilot study a similar approach was taken for the identification of any new factors. If interviewees used terms such as “must be in place; its vital that; Its critical that; it absolutely wont work unless: then these items were carried forward as potentially critical factors for further examination. In addition, social clues such as intonation were used to confirm what the interviewee viewed as critical.

3.2 Pilot Study

According to Bryman (2004) it is always desirable to conduct a pilot study before administering a structured interview schedule. It was also felt that a pilot study would be beneficial for the following reasons:

- To test whether all the identified factors from the literature were relevant given that the focus would be exclusively on construction.
- To allow the opportunity to explore whether the interviewees felt that there were additional relevant factors that were not found in the literature.
- To trial the interview questionnaire and technique.

3.2.1 Pilot Interview Approach

Lean is a concept. It is also the case that appropriate methods for the study of concepts would include grounded theory (Bryant and Charmaz 2010). However, the research question is quite specific in terms of identification of CSFs for Lean Construction. This led to a mix of qualitative approaches being deployed during the pilot study, including Theoretical Sampling (Bryant and Charmaz 2010).

3.2.2 Theoretical Sampling

Theoretical Sampling is a technique used within the grounded theory approach to understanding concepts by generating theory out of research data (Bryant and Charmaz 2010). One of the aims of the pilot was the identification of other potential CSFs not mentioned in the literature. Using this technique, any new possible CSFs were noted and coded until no new categories emerged, leading to "Theoretical Saturation". These factors were then carried forward into the main study for further testing.

Various interview techniques were considered and despite being the most expensive, face-to-face mode interviews were chosen over all others as the preferred technique for the following reasons:

- The complexity of the interview subject.
- The likely length of the interview.
- The ability to clarify the information sought if the question was not understood.
- The opportunity to include the grounded theory theoretical sampling approach as an initial part of the research by asking for narrative using open questions.
- The ability to detect social cues, including voice, intonation and body language.

The literature on the subject of interview methods is clear in that whilst face-to-face interviews are the most expensive and time consuming for all involved, they are likely to provide the highest quality of data (Bryman 2004; Holbrook, Green and Krosnick 2003: Opdenakker 2006).

3.2.3 Pilot Interview Design

In order to gain as much useful data as possible from the pilot study, the interview method chosen was qualitative and semi-structured in form. At this stage structured interviews were rejected as unsuitable due to the exploratory nature of the research. The interview was broken into two parts and recorded to digital media for transcription:

- Part One. The interviewee was asked to think of a specific construction project or process where they had attempted a lean intervention and asked simply to tell the story of what happened.

- Part Two. This consisted of a list of the critical success factors found in the literature. If presence or absence of any of these factors was not obvious from the initial narrative, further questioning took place until the relevance of all these factors could be established.

In addition to the search for the presence of the Critical Success Factors already found in the literature and any new factors considered by those interviewed as important, it was also felt important to examine how the interviewees defined success. This is because of the lack of a satisfactory definition of lean, i.e. it might be impossible to ask “Was it lean?” as this could mean a whole host of immeasurable concepts. However by asking “Did the efforts succeed?” the interviewer could elicit in depth answers that could late be analysed.

There were several reasons for the two-part approach:

- Using a narrative in part one would allow the interviewees the opportunity to express their views with the minimum of influence from the researcher.

- A narrative would allow any new CSFs to emerge unprompted.

- The second part was necessary to test for the presence of the factors identified in the literature if not obvious from the narrative, as well as collecting descriptors of success.

3.2.4 Pilot Interviewee Profiles

Six senior personnel from both the private and public sectors were invited to contribute, four of whom worked at director level. The types of construction work covered by the group included commercial new build construction, civil engineering, utilities and social housing maintenance. Three of those interviewed held full time jobs concerning construction best practice and innovation and all involved were known to have personally taken part in several attempts at applying lean construction. Two of the organisations had a turnover approaching £1billion in 2010.

3.2.5 Pilot Study Analysis

The recorded interviews were transcribed and analysed in sequence following both a theoretical sampling approach (Bryman 2004) to any new CSFs and a coding approach to keywords or themes (CSFs from the literature) in the second section. By the time the sixth interview had taken place and was coded, it was felt that theoretical saturation had been achieved in terms of the identification of any new CSFs and also in the way that the interviewees described (defined) success. This is defined to have occurred when no new categories emerge.

The pilot study led to several outcomes:

- CSFs from the literature were either confirmed or dropped.

- New possible CSFs were identified for further investigation.

- Success descriptors were collected.
- The summary analysis informed the questionnaire designed for the wider study.

3.3 Impact Of The Pilot Study And Literature Review On Main Study

The main study consisted of a larger sample of interviews carried out in a more focused fashion. It also deliberately set out to find both successful and failed interventions in order to test for the presence of the CSFs in each case and perform a comparison where possible. With this in mind, each factor from the pilot study was examined and a strategy formed for further examination. Only one of the interviewees considered their improvement project to be a failure. This section focuses on the results related to the factors identified in the literature.

3.3.1 There must be a crisis

It may be of interest to note that the economic climate for construction was harsh in mid 2010 when these interviews took place. This factor was only evident in one of the six interviews but all six chose to conduct the lean interventions out of choice rather than necessity. However, because it was important to one respondent it was decided to keep this question going forward into the main study.

This led to the hypothesis:

A crisis is necessary for lean construction to succeed

And a null hypothesis:

A crisis is not necessary for lean construction to succeed

Carried forward into the main study, a simple present/not present binary examination of this factor was chosen. This would be tested in further interviews by means of open questioning, because a scaled approach to different levels of crisis seemed superfluous. The new question to be asked in a structured interview format was “What prompted you to start the intervention?” If a definitive decision on the presence or absence of the factor could not be taken from the response, a more specific question or form of probing was used such as “Did you feel you had to do this because of external pressures or did you choose to do it?” This method produced binary data that could be tested for significance.

3.3.2 There must be buy-in from the improvement team

The pilot study respondents were unanimous that this was important.

This led to the hypothesis:

Buy-in from the improvement team is critical for success

And a null hypothesis:

Buy-in from the improvement team is not critical for success

It was decided to take the examination of this factor forward with a more structured approach to attempt to establish the degree of importance or weighting respondents attributed to it.

A new question was formed utilising a scaled response approach thus:

“What was the level of buy-in from the improvement team?”

3.3.3 There must be buy-in from senior management

The pilot study respondents were unanimous that this was important.

This led to the hypothesis:

Buy-in from senior management is critical for success

And a null hypothesis:

Buy-in from senior management is not critical for success

It was decided to take the examination of this factor forward with a more structured approach in order to attempt to establish the degree of importance or weighting respondents attributed to it.

A new question was formed using a scaled response approach thus:

“What was the level of buy-in from senior management?”

3.3.4 Improvement efforts must be process, not result focused to succeed

All but one pilot study interviewee said their efforts were results focused. No clear pattern emerged because some activity that appeared process focussed to the researcher was reported as results focused by the interviewee. This mode of questioning did not work by asking if the efforts were result or process focused as there was too much confusion in deciding which was which.

Most that declared their efforts “result” focused had experienced successes contrary to the process focused approach recommended in the literature.

Interestingly, the only person who said process focussed probably had the most successful outcome with a 15 per cent annual cost reduction and halving of lead time which had been sustained.

This factor proved relevant but the question was not clear enough, with some respondents appearing to answer something else but not the intended question.

A hypothesis was formed:

Lean Construction must be process focused to succeed

And a null hypothesis:

Lean Construction does not need to be process focused to succeed

Due to the difficulties encountered in the pilot study a new way of testing for the presence of this factor was conceived.

Interviewees would be asked to choose which of the following statements most closely fitted the focus of their improvement project.

- The aim is to simplify and reduce the number of steps required or remove waste, and generally improve the process, which we have faith will lead to a better result

  or:

- The aim is to improve performance from a to b with ‘a” being the lead time or cost or other tangible measurable result

This method would produce binary data that could be tested for significance.

3.3.5 Improvement goals must be set

It appears that improvement goals were set in all cases. One difference was in whom set the goals: was it the improvement team or were they externally imposed? In the one failed intervention the goals were very unclear and set by the team themselves. It is felt that this may well be a relevant factor that needs further exploration and was carried forward.

A hypothesis was formed:

It is critical that improvement goals are set

And a null hypothesis:

Setting improvement goals is not critical

The question was fairly straight forward and participants of an improvement activity would surely know if goals had been set or not. The question was formed: “Were improvement goals for the project set?” This would produce binary data that could be tested. For interests sake data would also be collected on the question of who set the goals.

3.3.6 The focus must be on the end user to succeed

Focus on the end user certainly appears in the lean literature as a central tenet. It is not clear however whether this is a critical success factor for lean construction. In many cases the customer that must be satisfied by the team is not the end user but more usually a client.

As previously stated, the pilot interviews relied on narrative and open questions to examine whether factors were present or not. Going forward into the main study a more focused approach was desired and so a new question was formed: “Thinking about the focus of the improvement project, who was the main stakeholder you were trying to please? For example, the client, the public or end user, or the boss?”

This would establish binary data on the presence or absence of the factor concerned.

A hypothesis was formed:

End user focus is necessary to succeed

And a null hypothesis:

End user focus is not necessary to succeed

3.3.7 The intervention must involve all stakeholders

Only one of the interviewees mentioned this. The importance of involving everyone in the process, however, is clearly stated in the SMMT Industry Forum common approach as a basic philosophy (Bateman 2001). There is a problem here with establishing just what "all" means. To one person it could mean a close knit team and to another, a whole supply chain. This potential CSF was carried forward to the main study with the question "Which stakeholders were involved in the improvement process?" This was followed by the subsequent question "If any were missing what effect did this have?"

This would allow a research decision to be taken as to whether the interviewee felt that "all" were present or not in the context of the particular improvement project in focus.

This would produce binary data.

A hypothesis was formed:

The intervention must involve all stakeholders to succeed

And a null hypothesis:

The intervention does not need the involvement of all stakeholders to succeed

3.3.8 Management must be capable

In no case did this factor emerge unprompted from the initial narrative. The questioning that followed was not specific enough and "capability" was found to be too loose a term to be meaningful without completely changing the research question and focusing on this point alone.

The responses split in two with some talking about process and some talking about people. There was also confusion with the concept of buy-in. The general consensus from the interviewees was that this factor is important. But what aspects in particular could mean capable? How could this be measured or tested for presence? It was decided to let the respondents in the main study decide what capability meant by asking:

- "What particular management skills or attributes do you think are essential for a lean intervention?"

Followed by:

- "Were these skills present in your improvement team?"

This would produce information as to what specific management skills for lean the interviewees considered important and also binary data as to whether these skills were present or not during the improvement efforts.

A hypothesis was formed:

Capability of management is critical for success of a lean intervention

And a null hypothesis:

Capability of management is not critical for success of a lean intervention.

3.3.9 Senior Management must be directly involved

The interviewees were unanimous that hands on involvement from senior management made a big difference. The question "Were senior management personally involved?"

seemed to work quite well and was carried forward to the main study. Binary data could be produced to test the hypothesis:

Direct senior management involvement is critical for a lean intervention to succeed

And a null hypothesis:

Direct senior management involvement is not critical for a lean intervention to succeed

In addition, it was felt that it would be useful to know what sort of things management actually did and this question was added to the main study.

3.3.10 Management must stay focused on the efforts

The interviewees were unanimous that this was important and also spoke generally about different interventions they had taken part in, rather than focusing on just one example. The question "How important is it that management should stay focused on the improvement efforts?" was carried forward to the main study with a scaled response question and a hypothesis was formed:

It is critical that management stays focused on the efforts to improve

And a null hypothesis:

It is not critical that management stays focused on the efforts to improve

3.3.11 Appropriate training is critical for success in lean interventions

There was consensus that training is important and that it happened to varying extents. The interviewees also talked about this subject in relation to more than one intervention. This was taken into account and carried forward into the main study with the scaled question “In the context of your Lean intervention/s, how important is specific training in the lean philosophy and techniques?” A hypothesis was formed:

Training in lean techniques is critical

And a null hypothesis:

Training in lean techniques is not critical

3.3.12 There must be a learning by doing approach

Two of those interviewed felt this was important. A learning by doing approach could quite easily be contrasted with classroom training. This was carried forward to the main study to examine the approach taken during successful interventions. A question was formed thus: “This question is about classroom training v teaching by doing, what sort of approach did the facilitator take?”

This would create binary data. A hypothesis was formed:

A learning whilst doing approach is critical for success

And a null hypothesis:

A learning whilst doing approach is not critical for success

3.3.13 Actions must be closed by the team

Two of those interviewed mentioned monitoring of actions being closed. However, any clear links with success or otherwise could not be established. It was decided to carry this forward to the main study to try to test the relationship between the extent actions were closed and whether they resulted in success or failure. The question “To what extent were the actions closed?” was formed with scaled responses leading to the hypothesis:

Closing of actions by the improvement team is critical for success

And a null hypothesis:

Closing of actions by the improvement team is not critical for success

3.3.14 People must be allowed enough time to spend on improvements

No clear answers were gained. The general consensus was that the day job gets in the way and that there is not enough time for improvement activity. In one instance, the company tried to measure the time invested in financial terms. Also in one interviewee's business they were spending vast amounts of time and things were getting worse. It would appear that this could be a relevant factor but there was no consistency between time spent and success. One interviewee spent little time yet had success, another spent a lot of time but failed. In fact there was an equal divide between "little time and success" and "lots of time but fail". It was decided to carry this question forward but to refine the approach to try to quantify how much time was necessary for success, and also whether success could be gained without taking any time out from the day job at all. Further, it was decided not to attempt to link this question to a particular intervention but to ask future respondents to consider the subject in a wider context. A two-part question was formed:

Part a) "How much of their time must people spend on an improvement activity for a successful outcome?" This would generate ordered category data using a scaled response.

Part b) "Can success be achieved without taking time away from work?" This would generate binary data.

A hypothesis was formed:

Staff must be allowed to take time out to spend on the improvement efforts

And a null hypothesis:

Improvement efforts can succeed without taking time out away from work

3.3.15 A high level of communication between suppliers is key

Much of the lean construction literature is concerned with the Last Planner System (Ballard 2000a). This system relies heavily on enhancing communication between suppliers or sub-contractors. In the pilot interviews, however, only one person talked about this. It was decided to carry this forward to the main study with the question:

“How would you describe the level of communication between the sub-contractors?”

The hypothesis was formed:

A high level of communication between suppliers is critical for success

And a null hypothesis:

A high level of communication between suppliers is not critical for success

3.3.16 Must overcome silo thinking to succeed

This factor assumes that silo thinking is present, although it may be the case that it was absent. Two of the interviewees spoke about this subject or its opposite – systems thinking. It was decided to carry this forward but to try and test whether it was present at all and if so to what extent this affected the outcome of the efforts. A hypothesis was formed:

Failure to overcome silo thinking will cause a lean intervention to fail

And a null hypothesis:

Failure to overcome silo thinking will not cause a lean intervention to fail

A four-part question was formed:

Part one asked, “to what extent was silo thinking present in your project?” with ordered category response options.

Part two asked, “to what extent did this affect your efforts?” this had with ordered category response options.

Parts three and four asked “what did you do about it this?” and “what happened as a result?” respectively. These would produce narrative data.

3.3.17 The intervention must be linked to a long term strategy

This was mentioned by three of the pilot study interviewees. However, no firm conclusions could be reached as to the effect of this on the success of the efforts to improve. It was felt that lean applied to a construction project or process might succeed or fail whether it was linked to a long-term strategy or not. Also within “long term strategies” there are highly likely to be some failures as well as successes and it is the difference between these that is of interest here. The relevance to the research was questionable so it was decided not to carry this factor forward.

3.3.18 There must be an organisation wide conversation about the proposed effort

From the pilot study there was no consensus that this factor is essential for a lean intervention, with successful outcomes being reported where clearly no “organisation wide conversation” took place. When respondents answered they referred to local teams rather than “organisation wide” or said that it did not take place at all. Given that five out of six interventions were successful the question was dropped.

3.3.19 An assessment of barriers to change must be carried out and an action plan formed

None of the pilot study respondents did this. Five out of the six projects were successful. One interviewee referred to some discussion taking place with one team. However, this was an isolated example and no real data were collected or analysed. It appears that this is not essential for success in the context of this research. This question was therefore dropped.

3.4 New CSFs Identified In The Pilot Study

As stated in the introduction to this Chapter, part of the purpose of the pilot study was to try to establish what other factors might be critical that were not already identified in the literature. To this end the first narrative-part of the interview used a grounded theory approach in order to identify new factors. These are listed below.

3.4.1 Relevant data must be available or created

Four of the six pilot study interviewees talked about the importance of data although the one failure did make a concerted effort to obtain data but still failed. Some repeatedly referred to the use of data. It was decided to carry this forward into the main study by first asking future interviewees: “What sort of data would be beneficial for improvement activity?”, followed by; “did you have any of this available for your project?” and “Did this help or hinder your efforts?” This would create narrative and binary data. A hypothesis was formed:

It is critical that relevant data are available or created

And a null hypothesis:

It is not critical that relevant data are available or created

3.4.2 More than one lean tool must be used to succeed

The subject of tools and techniques was mentioned by three of the interviewees, and in particular the notion that it was necessary to apply a range of tools rather than just one. This was carried forward to the main study with a two-part question:

Part a) "How many different improvement tools were used?"

Part b) "How important is it that more than one tool is used?"

A hypothesis was formed:

More than one lean tool must be used for success in lean construction

And a null hypothesis:

Success in lean construction can be achieved using only one lean tool

3.4.3 A long term client relationship or work stream is critical for success

Regular clients and long-term work-streams were seen as good enablers of lean or even key drivers. All interviewees seemed very keen on improvement when this condition was present.

It was decided to carry this forward with the following question: "This is about the influence the type of contract/client relationship may have on the success of an intervention? In other words, was it a long term client relationship?"

A hypothesis was formed:

A long-term client relationship or work-stream is critical for success

And a null hypothesis:

A long-term client relationship or work-stream is not critical for success

In addition to testing for the presence or absence of this factor it was felt that the level of influence a long-term client relationship had would merit further exploration. A secondary question was included: "What effect did this have?"

An additional hypothesis was formed:

A long-term client relationship or work stream will significantly influence the outcome of a lean intervention

And a null hypothesis:

A long-term client relationship or work stream will make no difference to the outcome of a lean intervention

3.4.4 There must be a high level of collaboration with sub-contractors

Four of the six pilot study interviewees thought this important. However, this assumes sub-contractor involvement in the lean improvement process and that might not always be the case. For example, an improvement project might focus on work that is undertaken by direct labour or possibly an internal process such as estimating. This was carried forward into the main study after modifying the question as follows:

"This question is about supply chain and is relevant if your efforts were project focused and needed sub/c":

a) "What was the level of collaboration like between suppliers?"

b) "What effect did this have?"

It would first be established whether the subject of sub-contractor collaboration was relevant to the particular improvement project in focus and then to examine the perceived level of collaboration and the effect this had on the outcome. A hypothesis was formed:

A high level of sub-contract collaboration is critical for success

And a null hypothesis:

A high level of sub-contract collaboration is not critical for success

3.4.5 The right facilitator is critical

Only one respondent mentioned this. It would appear that it is generally taken for granted that facilitators know what they are doing and the focus is on other factors or concerns. Future respondents may not be able to compare different facilitators. Nevertheless it could be critical. It was decided to carry this forward accepting the likelihood that not all future respondents in the main study might have experience of more than one facilitator. A new question was formed to find out firstly whether the respondent had experience of more than one facilitator and then to examine how important they felt this was to success as follows.

"Do you have experience of more than one lean facilitator/trainer?"

a) "If yes how important is the facilitator in ensuring success?"

b) "If a contrast exists between trainers what did the most successful one(s) do that the others didn't?"

In addition they would be asked to explain what sort of things the best facilitators did to establish their key traits/styles. The new question would need to relate to the general concept rather than just one intervention.

A hypothesis was formed:

The facilitator is critical to success

And a null hypothesis:

The facilitator is not critical to success

3.4.6 The age of the team

This was mentioned by only one of the pilot study interviewees but he was adamant that this was a real issue and during interview said; “They just didn’t want to change, they didn’t want to have to learn new process. They didn’t want to have to undo, because were talking about people who are generally in their 50’s.”

This was carried forward to the main study with the following question:

“Do you think that the age of the improvement team is a critical factor for success?”

- “How old is too old?”
- “How young is too young?”
- ”Why is this?”

A hypothesis was formed:

The age of the improvement team members is critical to success

And the null hypothesis:

The age of the improvement team members is not critical to success

3.4.7 There must be a no-blame culture to succeed

Despite being mentioned only once during interviewing, this is consistent with the researcher's own extensive experience particularly in public sector organisations. People habitually will not try new ways of working just in case it fails and they get into trouble.

This was carried forward to the main study with the following question:

"To what extent did a blame culture exist in your organisation during the efforts?" and

"Was anything done to address this?"

This was carried forward with the hypothesis:

There must be a no-blame culture to succeed

And a null hypothesis:

A no-blame culture is not necessary for success

3.5 Descriptors Of Success

It was felt important that the way that interviewees perceived success should be captured. The following success descriptors emerged from the initial story telling narrative of their improvement project.

- On time, snag free, happy client, time saving, cost saving, more profit and retained client relationship.

The number of pilot study interviewees that mentioned each descriptor is shown in Figure 3.1 below.

The descriptors appear readily translatable to standard measures of cost, quality, delivery and customer satisfaction. However it was decided to carry this examination of descriptions of success into the main study for interest's sake. In fact some questioning surrounding success would be essential to the main study to enable a distinction between both successes and failures. This would allow the hypotheses to be tested by contrasting which CSFs were present or absent. A scaled response question was formed; "Was the effort successful?" followed by; "How do you know that?" This would generate ordered category and narrative data respectively.

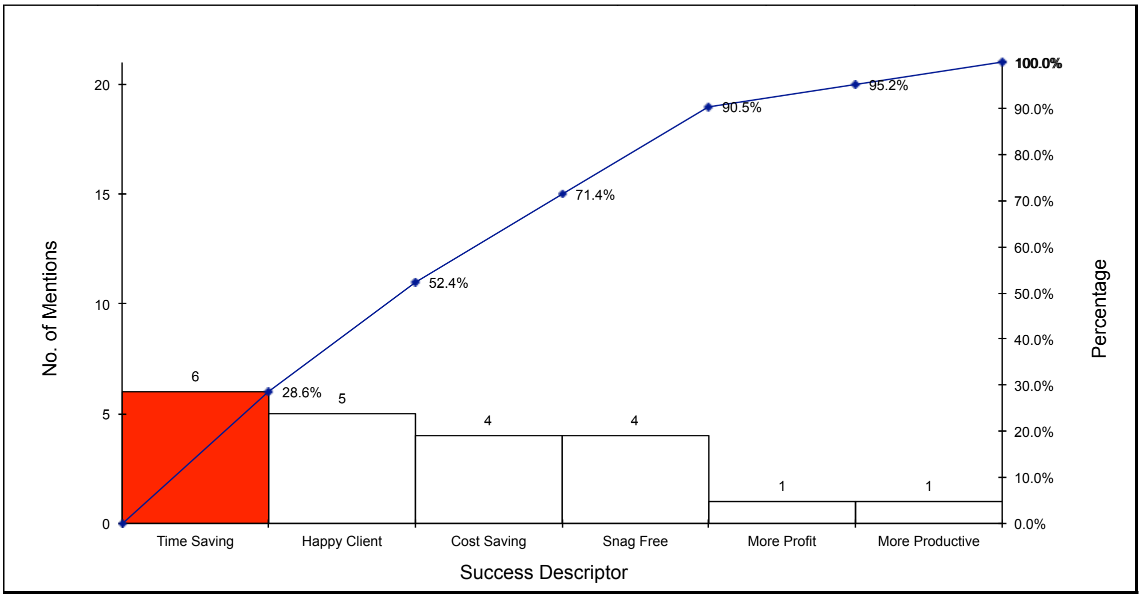

Figure 3.1 Descriptors of success from pilot study

3.6 Pilot Study Summary

The six pilot interviews yielded a rich data set. This was used to check the relevance of the critical success factors found in the literature review previously undertaken and also to identify new factors. It was also felt that the two stage semi-structured approach worked well for its intended purpose. Some of the potential CSFs were spoken about within the context of just one lean intervention effort whilst others tended to be referred to as a general concept. This was reflected in the design of the main study questionnaire.

Of the 19 CSFs identified in the literature 16 were chosen to be carried forward into the main study. In addition, a further 7 potential CSFs were identified. A revised set of Critical Success Factors was formed for further examination. This is shown in Table 3.1 below with the newly identified factors denoted with an N.

Table 3.1 Revised list of critical success factors

	Critical Success Factors/Hypothesis
1	A crisis is necessary for lean construction to succeed
2	Buy-in from the improvement team is critical for success
3	Buy-in from senior management is critical for success
4	Lean Construction must be process not results focused to succeed
5	It is critical that improvement goals are set
6	End user focus is necessary to succeed
7	The intervention must involve all stakeholders to succeed
8	Capability of management is critical for success of a lean intervention
9	Direct senior management involvement is critical for a lean intervention to succeed
10	It is critical that management stays focused on the efforts to improve
11	Training in lean techniques is critical for success
12	A learning whilst doing approach is critical for success
13	Closing of actions by the improvement team is critical for success
14	Staff must be allowed to take time out to spend on the improvement efforts
15	A high level of communication between suppliers is critical for success
16	Silo thinking will cause a lean intervention to fail
17 N	It is critical that relevant data are available or created And that availability of data will have a positive influence
18 N	More than one lean tool must be used for success in lean construction
19 N	A long-term client relationship or work stream is critical for success
20 N	A high level of sub-contract collaboration is critical for success
21 N	The facilitator is critical to success
22 N	The age of the improvement team members is critical to success
23N	There must be a no-blame culture to succeed

3.7 Other Main Study Interview Design Considerations

Due to the complexity of the overall subject and indeed some of the individual CSFs, a "one-size fits all" approach to questions would not do. A questionnaire approach was once again considered and dismissed in favour of further face-to-face interviews with a larger group. In order to answer the research question, the aim was to compare successful interventions with failures and establish which CSFs were present or most prevalent in each. To this end, after introducing interviewees to the study, the first question to be asked was "Was the effort successful?" This question was designed with an ordered category response and further clarified by asking "How do you know that?" which would produce narrative for later analysis. As discussed above, a new question or in some cases questions, were designed to explore each of the 23 CSFs in turn. Where it was considered appropriate, some scaled or binary responses were either preceded or followed by an open question that would produce narrative for further analysis. Other questions were designed first to establish the presence or absence of a factor, then to measure the importance the interviewee placed on this, resulting in both binary and scaled data for the same factor.

The questions would provide different types of data as shown in Table 3.2 below.

Table 3.2 Summary of data types that would be generated by questions

CSF	Linked to one particular intervention success or failure Y/N?	Categorical data	Binary data	Narrative
1	Y		Y	
2	Y	Y		
3	Y	Y		
4	Y		Y	
5	Y		Y	Y
6	Y		Y	
7	Y		Y	Y
8	Y		Y	Y
9	Y		Y	Y
10	N	Y		
11	N	Y		
12	Y		Y	
13	Y	Y		Y
14	N		Y	
15	Y			
16	Y	Y		Y
17	Y		Y	Y
18	N	Y		
19	Y	Y	Y	
20	Y	Y		
21	N	Y		Y
22	N		Y	Y
23	Y	Y		Y

3.7.1 Choice of scale

The preferred method was to generate binary responses without influencing the outcome, for example when asking the interviewee to describe what prompted them to start the intervention to test for the presence or absence of “crisis”. However this was not appropriate for all questions. For example, when looking at the concept of “buy-in”, this could happen at varying levels and so ordered category options were designed that would produce ordinal data. Whilst in the style of Likert, these are strictly speaking not either Likert points or scales, but “ordered category options” (Uebersax 2006). Although there are arguments in favour of seven category scales, the benefits appear very marginal

(Colman, Norris and Preston 1997) and five-category scales were chosen as the additional benefit of seven points was considered to be overshadowed by the increased complexity this would bring to the face-to-face interview technique. Odd numbers of categories were chosen to avoid any forced distributions. The completed set of questions used in the structured interviews can be found in Appendix 1.

3.8 Main Study Interviewee Profile

A list of construction personnel was formed that were known either to the researcher or his colleagues to have been directly involved in one or more lean interventions. A number of these people were contacted by email and invited to contribute to the research project. Thirty-one interviews took place with a mix of public and private sector, senior managers, middle managers and first line supervisors. This is shown below in Table 3.3. These interviews did not take place in any preferred order but according to geographic location and the convenience of both the interviewee and the researcher.

3.8.1 Sample Size

Key drawbacks of the face-to-face interview technique are both the time and cost involved, not only in carrying out the interviews but also in the transcription, coding and analysis of the resultant data. As previously stated, this was the preferred method for obtaining the richest data set. To compound this issue the research called for analysis of both successes and failures that would be analysed as two groups and compared to examine the influence of each of the 23 CSFs.

Table 3.3 Profile of interviewees

Interview No.	Succeed or Fail?	Public Sector	Private Sector	Senior Manager	Middle Manager	First Line Supervisor
1	F	X		X		
2	S	X		X		
3	S	X		X		
4	S	X			X	
5	S		X	X		
6	F		X		X	
7	F	X			X	
8	S	X		X		
9	S	X				X
10	S		X		X	
11	S	X			X	
12	S	X			X	
13	S		X		X	
14	S	X			X	
15	S	X			X	
16	S		X	X		
17	S		X	X		
18	S		X		X	
19	S		X			X
20	S		X	X		
21	S		X			X
22	S		X	X		
23	F		X			X
24	F		X		X	
25	S		X		X	
26	S		X	X		
27	S		X	X		
28	S		X	X		
29	F		X	X		
30	S		X	X		
31	S		X			X

A minimum sample size that would be capable of providing statistically significant results was sought. As can be seen in table 3.3 above, the interview process progressed until 6 failures and 25 successes were found.

According to Norman (2010: 4):

> "[S]*mall samples require larger effects to achieve statistical significance. But to say, as one (academic) reviewer said above, ''given the small number of participants in each group, can the authors claim statistical significance?'' simply reveals a lack of understanding. If it's significant, it's significant. A small sample size makes the hurdle higher, but if you've cleared it, you're there.*"

It would also appear that there is no set definition of what “small” means. However, different types of statistical tests tend to carry differing recommendations for sample size and this was taken into account in the selection of the tests used for the purpose of this research. Winter (2013) provides a useful discussion of the differences of opinion amongst statisticians regarding sample size and of various tests and their reliability with small sample sizes, sometimes less than 4.

3.9 Resultant Data Sets And Methods Of Analysis

All interviews were recorded to digital media and transcribed into text. Four sub-sets of data were split into:

- Responses that could be linked directly to failures.
- Responses that could be linked directly to successes.
- Responses that were the opinion of the interviewees about how important a factor was, but not linked to any particular failure or success.
- Narrative responses that provided further clarification.

3.9.1 Types of Data

Three types of data were generated from the interviews as shown above in Table 3.3: ordinal data from the ordered categories; binary data when testing just for presence or absence of a factor; and transcribed narrative mainly used to further enhance and clarify the responses. The approaches to these are dealt with in turn below.

3.9.2 Narrative Text Analysis Method

The text for each question that required a narrative response or verbal clarification was copied from each individual interview and grouped into separate documents so that all responses to the same question could be viewed at once. Key words were then recorded in an Excel spreadsheet and the frequency with which these were mentioned was recorded. Where appropriate and if thought to add value, a graphical representation of the data in the form of a Pareto analysis was used. The results of the narrative were not intended to stand alone but to enhance or further explain some of the other data sets.

3.9.3 Ordinal data analysis method for CSF data linked to success or failure

The scaled response questions devised resemble Likert type responses but they are not. Working from the transcribed text, each C*ategory Ordered Item* was given a number from 1 – 5 and input into a spreadsheet. Separation into successes, failures, or "not linked to one intervention" stratified the data further and created a nominal input variable for successes and failures. A key characteristic of the output ordinal data produced is that the response categories have a rank order but the intervals between values cannot be presumed equal. For example, the difference between 1 – *none* and 2 – *a little*, cannot be said to equal the difference between 4 – *quite a lot* and 5 – *substantial*.

Jamieson (2004) quotes many published research examples of how incorrect statistical methods have been used to test categorical data, in particular the common mistake of treating categorical data as though it were interval data. Jamieson (2004:1218) goes on to paraphrase Kuzon Jr et al. with "the average of "fair" and "good" does not equal "fair and a half". Another key characteristic is that distributions of such data are often found to be skewed and non-normal (Boslaugh 2012; Bryman 2004; Jamieson 2004). Under these circumstances, parametric techniques such as the use of means, standard deviations and ANOVA are said to be inappropriate by most, and non-parametric techniques are recommended. However Norman (2010) goes against the grain and refutes the common assumption that parametric tests cannot be used for ordinal data, stating that the real issue is one of "robustness", i.e. does the test give a reliable answer. He concludes that one can indeed use parametric tests for ordinal data, whether normally distributed or not, and with small sample sizes. In other words, whilst it is true that the intervals between the categories cannot be assumed equal, in practice this may not affect the result.

Yet another consideration key to this research was the fact that whatever test was used it would also have to deal with unequal sample sizes, with the data set consisting of 25 successes and 6 failures.

The characteristics of the data in focus are:

- Input data – failure or success = Nominal Input Variable.
- Output Data – Ordered category items = Ordinal Output Variable.
- Independent measures.
- Unequal sample size.
- Relatively small sample size in Failure Group(s).
- For the majority of factors, it was necessary to test only in one direction, i.e. is it critical? Therefore one tailed tests sufficed. However two of the questions required two tailed tests. These were;
    - "What effect did this have?" (after testing for the presence of a long term client or workstream) and
    - "What effect did this have?" (after testing for the level of collaboration between suppliers).

For clarity two tailed tests were necessary as the effect in focus may have been positive or negative.

A search for a suitable test with these data concluded that a one-tailed Mann Whitney U Test was the most appropriate (Anderson, Jong-Min and Engin 2004; Boslaugh 2012; Campbell 2006).

The Mann Whitney Test is a non-parametric test used to test the null hypothesis that the distributions of two unpaired groups are identical, and assumes there is a 50 per cent probability that an observation from a value randomly selected from one population exceeds an observation randomly selected from the other population. The test produces a P value that is usually set at *alpha* 0.1, 0.05 or 0.01. A result producing a P value less than the set *alpha* level will reject the possibility of a difference being possible due to chance. This would allow the following CSF results to be tested for significance: 2, 3, 13, 15, 16, 19, 20 and 23. *X*LSTAT software from Addinsoft was used for the Mann Whitney tests. This software provided the most flexible options in terms of choice of confidence interval *alpha,* the method of P value calculation and the application of one or two tailed tests. The three methods of P value calculation this software offers are:

- The Exact Method.
- The Monte Carlo Method.
- The Asymptotic Method.

Following a review of the appropriateness of each of these for the data set in hand, the Exact Method was chosen as the most robust.

3.9.4 Ordinal data analysis for CSF data not linked to success or failure

This includes data from CSFs 10, 11, 18, and 21 which was obtained from all 31 interviews. Only one group of data was produced. It related mostly to interviewees that had experienced more than one lean intervention. They were asked for their opinion of the relative importance to success of the factor in question. Given the discussion above about using parametric tests for ordinal data, the following statistics were computed for these CFSs.

The mode and median, per cent level above 4 and mean – as discussed above. Strictly speaking ordinal data cannot have a mean, only a median and a mode, although this would also be computed for comparative purposes. Further, given a larger sample size of 31 interviews, the number of interviewees that reported a higher score than 4 would be reported. Within the Likert style questions, 4 usually meant “important” and 5 “vital” If greater than 90 per cent of answers were 4 or 5, then this could contribute to a conclusion as to whether the factor in focus was critical or not. In addition, a suitable statistical test for this data set was found to be a One–Sample Wilcoxon Signed Rank Test. This is a non-parametric alternative to a one-sample t-test that can be used with non-normal data, which is usually the case with ordered category data (Boslaugh 2012; Pappas and DePuy 2004). In this test a hypothetical value for the median is chosen, and the test produces an estimate of the probability that the data in focus will equal the median.

The factors in focus here contain ordered category data with a five-point scale, with 3 being the median. An upper tailed test was used to check the level of statistical significance and allow the null hypothesis to be tested thus:

H0: m < mo, where mo is the specific value of the population median to be tested, in this case 3, against the alternative hypothesis H1 : *m > mo*.

3.9.5 Binary data Analysis Method for Data linked to Success or Failure

This concerns CSFs 1, 4, 5, 6, 7, 8, 9, 12, 17, 18 and 19.

Two groups were formed in a two by two contingency table thus:

Table 3.4 Two by two contingency table

Hypothesis test		
	Sucesses	Failures
Factor Present	n_1	n_2
Not Present	n_3	n_4

The aim was to check whether the levels of each factor present or absent in each group were statistically significant in order to test the hypotheses.

The tests most suitable for this type of data were found to be either the Chi Squared Test or Fishers Exact Test (Boslaugh 2012). The Chi Squared Test was said to be best if any expected number used would be greater than 5. It appears, however, that this arose before the advent of computers when using numbers greater than 5 would require tedious manual calculations that were prone to error (McDonald 2014). McDonald carried out a useful experiment to explore the effect of sample size on binomial tests, concluding that for any sample size of less than 1000, the exact tests are more accurate than Chi Squared. He also concluded that Fishers test produces more conservative results.

As a result, Fishers Exact test was chosen. This test calculates the probability of obtaining the observed results by chance, and forms the null hypothesis that no significant difference exists between the two groups. The test used was two tailed, although it was only of interest to note if the Success Factor in focus was critical or not. The reported results are *P* values, and if 0.1 or less, the null hypothesis would be rejected and therefore the alternative hypothesis be accepted and the factor in focus would be found to be critical.

3.9.6 Binary data analysis method for data not linked to success or failure

This concerns CSFs 14 and 22.

The results will show what proportion of the interviewees considered these factors critical. This will be reported as a percentage. Suitable tests for significance for these non-parametric data were found to be Binomial and Sign tests. However, a one-sample Z test was eventually selected as more robust with the larger sample size of 31 data points. With this sample size the Z test whilst parametric assumes a normal distribution approximation (Batali 2007).

3.9.7 Confidence Level

The chosen acceptable confidence limit for the hypotheses was set at 0.9. The choice of confidence level is arbitrary (Filliben 2012), but this level was felt to be reflective of the purpose and nature of the research project, i.e. to be able to provide practical guidance on which factors are most critical for a lean construction intervention in an organisation. In addition, it has been stated that there is a difference between practical significance and statistical significance, and a particular risk exists with large sample sizes that a hypothesis test will detect small differences leading to both type I and type II errors. It then follows that with small sample sizes that are in practice more robust (because to detect a real difference the difference must be significant by default), it should be acceptable to choose a slightly lower than usual confidence limit (Smith 2011).

CHAPTER 4 - RESULTS

4.1 Layout of Results

Chapter 3 set out the success descriptors from the pilot study in Figure 3.1 and identified 23 possible CSFs in Table 3.1. It went on to explain several methods for analysis. The results section will begin with the success descriptors from the main study before reporting the results from the 23 CSFs in turn.

In total 31 interviews were conducted. Twenty-five interventions were successful, with 6 interventions that either failed or were only partially successful. Using a binomial sign test the probability of obtaining 25 out of 31 successes by chance is < 1%.

4.2 Descriptors of Success

After declaring their lean intervention to be a success or a failure, the interviewees were asked how they had come to that conclusion. The frequency of keywords describing success is presented in Figure 4.1 below. Some respondents mentioned more than one descriptor and this accounts for a total of 53 mentions from 31 respondents.

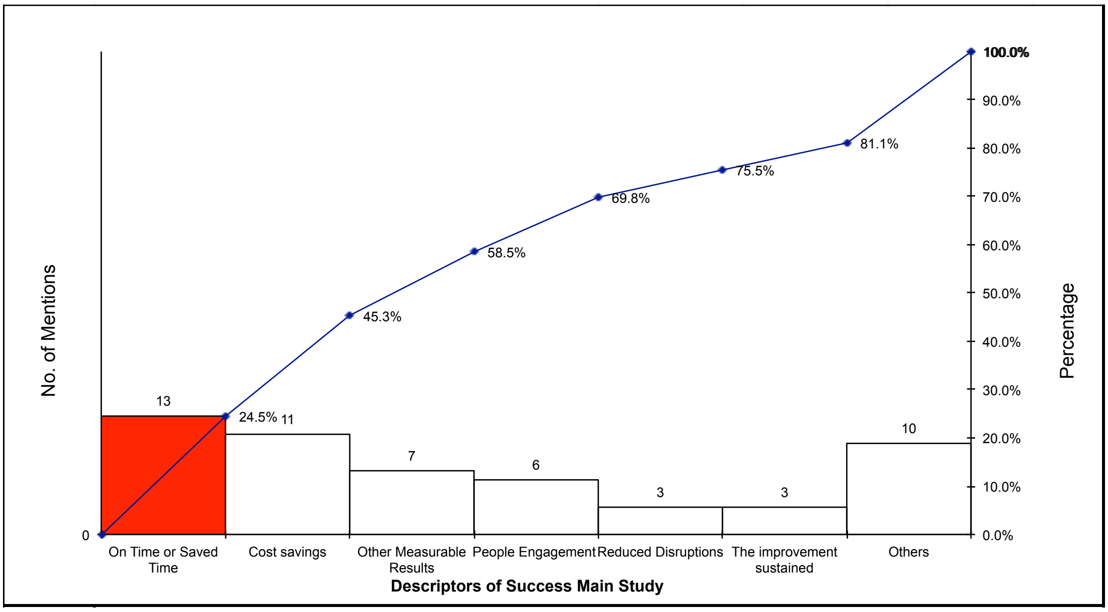

Figure 4.1 Frequency of keywords describing success

About 70 per cent of all mentions describing success accounted for the top four categories:

- On Time or Saved Time – 25 per cent.
- Cost Savings – 21 per cent.
- Some Other *Measurable* result – 13 per cent.
- People Engagement – 11 per cent.

Descriptors included in the "Other" category in the chart above were:

- Provide More Jobs – two mentions.
- More Efficient – two mentions.
- Quality Improved – one mention.
- Reduced Risk – one mention.

The percentage of respondents that mentioned a particular keyword rather than the overall number of mentions is shown in Figure 4.2 below. The percentages in Figure 4.2 do not add upto the sum of 100 per cent as some respondents mentioned more than one descriptor. The top four categories were:

- On Time or Saved Time – 42 per cent.
- Cost Savings – 35 per cent.
- Some Other *Measurable* result – 23 per cent.
- People Engagement – 19 per cent.

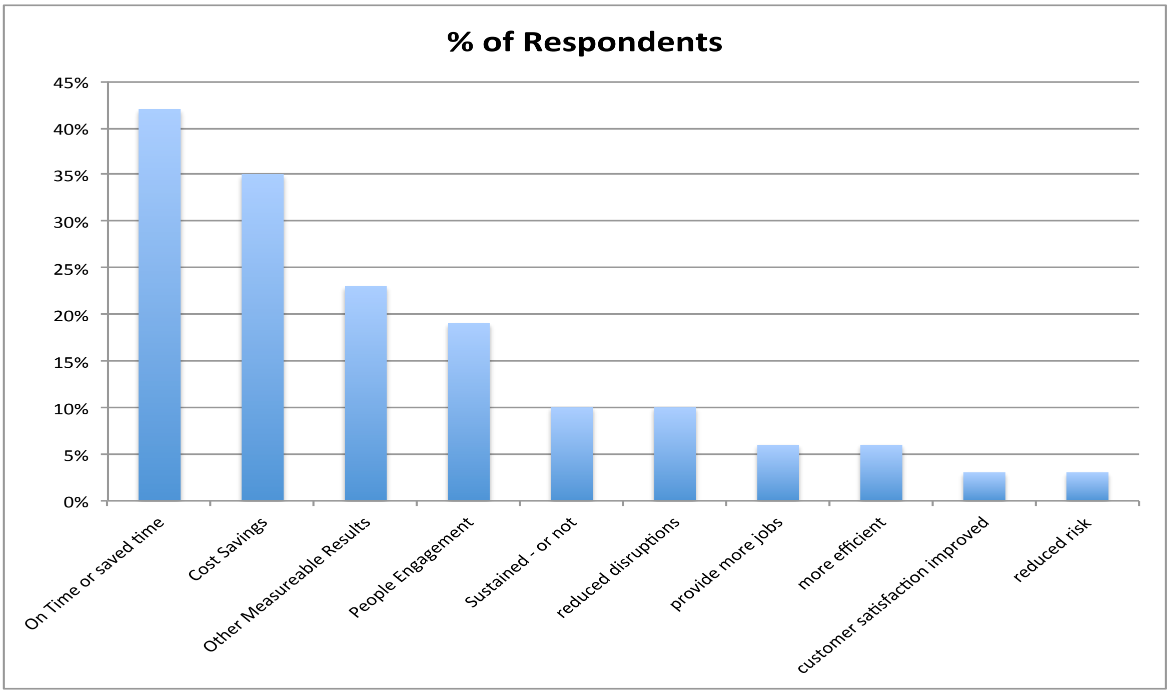

Figure. 4.2 Percentage of respondents that mentioned each descriptor of success

The number of respondents that mentioned the other categories in the chart above was:

- Sustained or not – three respondents.
- Reduced disruptions – three respondents.
- Provide more jobs – two respondents.
- More efficient – two respondents.
- Customer satisfaction improved – two respondents.
- Reduced risk – one respondent.

4.3 Factor 1 - A Crisis is Necessary to Succeed

In Section 3.3.1, a hypothesis was formed:

A crisis is necessary for lean construction to succeed

And a null hypothesis:

A crisis is not necessary for lean construction to succeed

The Results from Fishers Exact Test are shown in Table 4.1 below.

Table 4.1 Fisher test results for factor one

Fishers Exact Test		
	P-value:	0.298
	successes	failures
Factor Present	8	0
Not Present	17	6

The P value is > 0.1 so the Null Hypothesis is accepted and the factor is found not likely to be critical for Lean Construction to succeed.

4.4 Factor 2 - There must be buy-in from the improvement team

In Section 3.3.2 the hypothesis was formed:

Buy-in from the improvement team is critical for success

And a null hypothesis:

Buy-in from the improvement team is not critical for success

The results from a single tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.2 below.

Table 4.2 - Mann Whitney test for factor two

Mann-Whitney test / Upper-tailed test:	
U	118.000
Expected value	75.000
Variance (U)	348.871
p-value (one-tailed)	0.013
alpha	0.1
The p-value is computed using an exact method	

XLSTAT Test output:

As the computed p-value is lower than the significance level alpha = 0.1, the null hypothesis is rejected in favour of the alternative. The risk to rejecting the null hypothesis when it is in fact true is lower than 1.33%

With the null hypothesis rejected in favour of the alternative, the factor is found to be critical.

4.5 Factor 3 - There must be buy-in from senior management

In Section 3.3.3 the hypothesis was formed:

Buy-in from senior management is critical for success

And a null hypothesis:

Buy-in from senior management is not critical for success

The results from a single tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.3 below.

Table 4.3 – Mann Whitney test for factor three

Mann-Whitney test / Upper-tailed test:	
U	116.000
Expected value	75.000
Variance (U)	341.129
p-value (one-tailed)	0.070
alpha	0.1
The p-value is computed using an exact method	

XLSTAT Test output:

As the computed p-value is lower than the significance level alpha = 0.1, the null hypothesis is rejected in favour of the alternative. The risk to rejecting the null hypothesis when it is in fact true is lower than 7.01%.

With the null hypothesis rejected in favour of the alternative, the factor is found to be critical.

4.6 Factor 4 - Improvement efforts must be process, not result focused to succeed

In Section 3.3.4 the hypothesis was formed:

Lean Construction must be process focused to succeed

And a null hypothesis:

Lean Construction does not need to be process focused to succeed

The results from Fishers Exact Test are shown in Table 4.4 below.

Table 4.4 – Fishers test for factor four

Fishers Exact Test		
	P-value:	1.
	successes	failures
Factor Present	16	4
Not Present	9	2

The P value is > 0.1 so therefore the Null Hypothesis cannot be rejected and the Factor is not proven to be critical for Lean Construction to succeed.

4.7 Factor 5 - Improvement goals must be set

When goals were set they were either established by the improvement team themselves – 58 per cent, a senior manager or director – 29 per cent or the client – 12.5 per cent.

In Section 3.3.5 the hypothesis was formed:

It is critical that improvement goals are set

And a null hypothesis:

Setting improvement goals is not critical

The results from Fishers Exact Test are shown in Table 4.5 below.

Table 4.5 Fisher test for factor five

	P-value:	0.596
	successes	failures
Factor Present	20	4
Not Present	5	2

The P value is > 0.1 so therefore the Null Hypothesis cannot be rejected and the Factor is not proven to be critical for Lean Construction to succeed.

4.8 Factor 6 - The focus must be on the end user to succeed

In Section 3.3.6 the hypothesis was formed:

End user focus is necessary to succeed

And a null hypothesis:

End user focus is not necessary to succeed

The results from Fishers Exact Test are shown in Table 4.6 below.

Table 4.6 – Fishers test for factor six

	P-value:	1.
	successes	failures
Factor Present	5	1
Not Present	20	5

The P value is > 0.1 so therefore the Null Hypothesis cannot be rejected and the Factor is not found to be critical for Lean Construction to succeed.

4.9 Factor 7 - The intervention must involve all stakeholders

In Section 3.3.7 the hypothesis was formed:

The intervention must involve all stakeholders to succeed

And a null hypothesis:

The intervention does not need the involvement of all stakeholders to succeed

The results from Fishers Exact Test are shown in Table 4.7 below.

Table 4.7 – Fishers test for factor seven

	P-value:	0.383
	successes	failures
Factor Present	10	1
Not Present	15	5

The P value is > 0.1 so therefore the Null Hypothesis cannot be rejected and the Factor is not found to be critical for Lean Construction to succeed.

4.10 Factor 8 - Management must be capable

In response to the question "What particular management skills or attributes do you think are essential for a lean intervention?" 31 respondents generated 20 types of skills or attributes. Some respondents cited more than one type and overall 48 data points were created. The descriptions of attributes used by respondents to assess capability are presented in the order most frequently mentioned in Table 4.8 below.

Table 4.8 Respondents descriptions of management capability

Skill or Attribute	**Number of mentions**
The ability to get buy-in	11
Fosters teamwork	5
Be open minded	4
Willing to listen	4
Understanding strengths and weaknesses in the team	3
Provide direction	2
Engender trust	2
Can show understanding and empathy	2
Able to visually communicate information to get things done	2
Project Management	2
Able to motivate	2
Willingness to fail/no fear of failure	1
A can do attitude	1
Problem solving	1
Assertiveness	1
Able to adapt	1
McGregor "Y" approach	1
Ability to put the team at ease	1
Ability to involve everybody	1
A Broad Vision	1
Total	**48**

A chart of the most cited Skills or Attributes is shown in Figure 4.3 below.

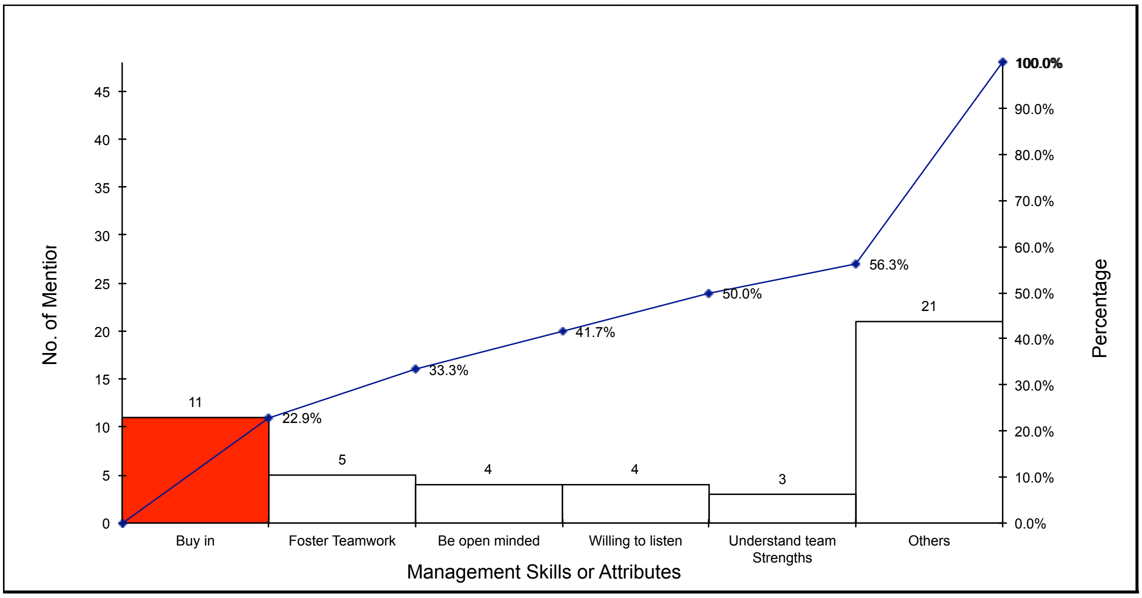

Figure 4.3 - Most frequently mentioned management skills and attributes

In total twenty different skills or attributes were mentioned. Of these, five accounted for 56 per cent of the data:

- Ability to gain buy-in - 23 per cent.
- Ability to foster teamwork - 10 per cent.
- Being open minded – 8 per cent.
- Willing to listen – 8 per cent.
- Ability to understand team strengths and weaknesses – 6 per cent.

In Section 3.3.8 the hypothesis was formed:

Capability of management is critical for success of a lean intervention

And a null hypothesis:

Capability of management is not critical for success of a lean intervention

Fishers exact test was used to test the binary data generated in response to the question "Were these skills present in your improvement team?" and the result is shown in Table 4.9 below.

Table 4.9 Fishers test for factor eight

	P-value:	0.034
	successes	failures
Factor Present	24	4
Not Present	0	2

The P value is < 0.1 so therefore the Null Hypothesis is rejected in favour of the alternative. The factor is found to be critical for Lean Construction to succeed.

4.11 Factor 9 - Senior Management must be directly involved

In Section 3.3.9 the hypothesis was formed:

Direct senior Management involvement is critical for a lean intervention to succeed

And a null hypothesis:

Direct senior management involvement is not critical for a lean intervention to succeed

The results from Fishers Exact Test are shown in Table 4.10 below.

Table 4.10 – Fishers test for factor nine

Fishers Exact Test		
	P-value:	0.067
	successes	failures
Factor Present	16	1
Not Present	9	5

The P value is < 0.067 therefore the Null Hypothesis is rejected in favour of the alternative. The factor is found to be critical for Lean Construction to succeed.

Respondents who reported that management were directly involved were asked what sort of things management actually did.

Seventeen respondents who reported that management were directly involved produced thirty-one data points spread over six categories. These were:

- Provided visible support – 35 per cent.
- Joined in the activity with the team – 23 per cent.
- Initiated the improvements – 16 per cent.
- Monitored progress -13 per cent.
- Personally led the improvements – 6 per cent.
- Challenged the thought processes – 6 per cent.

A summary of the responses together with the frequency of mentions are shown in Figure 4.4 below and provide an indication of the most important things that management can do to help.

4.12 Factor 10 - Management must stay focused on the efforts

In Section 3.3.10 the hypothesis was formed:

It is critical that Management stays focused on the efforts to improve

And a null hypothesis:

It is not critical that management stays focused on the efforts to improve

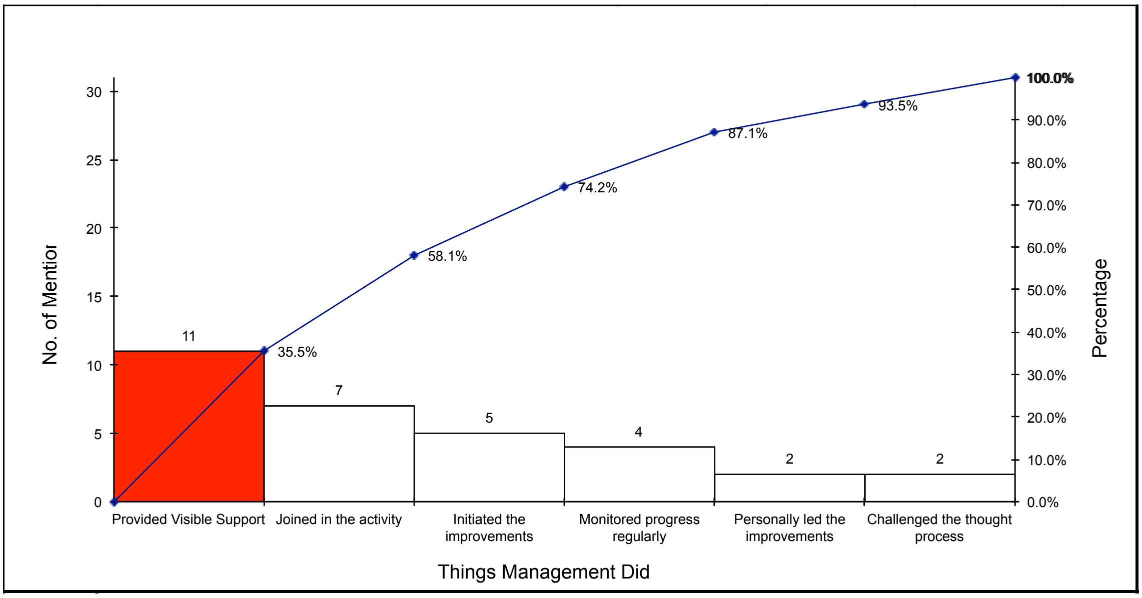

Figure 4.4 Things management did to help

This question was not linked directly to either success or failure but rather represented the opinion of all 31 respondents. Responses to the question "How important is it that management should stay focused on the improvement efforts?" were categorised as *Unimportant, Of little Importance, Don't know, Important and Vital* and coded 1 to 5.

The results of the 31 responses are shown in Table 4.11 below.

Table 4.11 – Results from factor ten

Mode	5.00
Median	5.00
Mean	4.83 or 97%
% That said Important (4)	16%
% That said Vital (5)	84%

An upper tailed test for significance was carried out using a one-sample Wilcoxon signed rank test using the mid level hypothesis of 3 which equals “don’t know” in the ordered rank question. The result was conclusive with a confidence level of more than 99 per cent. The output is shown in Table 4.12 below.

Table 4.12 Wilcoxon test results for factor ten

The One-Sample Wilcoxon Signed-Rank Test			
Observations Processed:	31	**The Test Procedure**	
Hypothetical Value (mu0):	3		
Average of Input Data:	4.8	Test Statistic (S+):	496
Median of Input Data:	5	Significance Level:	0.01
Standard Deviation:	0.37		
		Right-Tailed Test (Normal Approximation)	
Nb. of Zero Differences:	0	Z Stat:	4.86
Nb. of Tie Series:	2	Z Stat (Cont.-Adj.):	4.85
Mean Nb. of Ties/Series:	15.5	Z Stat (Tie-Adjusted):	5.24
		P-Value:	5.87×10^{-7}
Rank Sum:	496	Critical Value:	2.326
Rank Average:	16	Decision Rule:	Reject H0 if z > 2.326
			H0 Must be Rejected

Based on the data in Table 4.11 and the output shown in Table 4.12 the null hypothesis is rejected in favour of the alternative and the Factor is found to be critical.

4.13 Factor 11 - Appropriate training is critical for success in lean interventions

In Section 3.3.11 the hypothesis was formed:

Training in lean techniques is critical

And a null hypothesis:

Training in lean techniques is not critical

This question was not linked directly to either success or failure but rather represented the opinion of all 31 respondents. Responses to the question "In the context of your lean intervention/s, how important is specific training in the lean philosophy and techniques?" were categorised as *Unimportant, Of little Importance, Don't know, Important and Vital* and coded 1 to 5.

The results of the 31 responses are shown in Table 4.13 below.

Table 4.13 – Results from factor eleven

Mode	4.00
Median	4.00
Mean	4.26 or 85%
% That said Important (4)	52%
% That said Vital (5)	42%

An upper tailed test for significance was carried out using a one-sample Wilcoxon signed rank test using the mid level hypothesis of 3, which equates to "don't know" in the ordered rank question. The result was conclusive with a confidence level of more than 99 per cent. The output is shown in Table 4.14 below.

Table 4.14 – Wilcoxon test of factor eleven

The One-Sample Wilcoxon Signed-Rank Test				
Observations Processed:	31	**The Test Procedure**		
Hypothetical Value (mu0):	3			
Average of Input Data:	4.25	Test Statistic (S+):		462.5
Median of Input Data:	4	Significance Level:		0.01
Standard Deviation:	0.89			
		Right-Tailed Test (Normal Approximation)		
Nb. of Zero Differences:	0	Z Stat:		4.2
Nb. of Tie Series:	2	Z Stat (Cont.-Adj.):		4.19
Mean Nb. of Ties/Series:	15.5	Z Stat (Tie-Adjusted):		4.33
		P-Value:	1.31×10^{-5}	
Rank Sum:	496	Critical Value:		2.326
Rank Average:	16	Decision Rule:	Reject H0 if z > 2.326	
			H0 Must be Rejected	

Based on the data in Table 4.13 and the output shown in Table 4.14 the null hypothesis is rejected in favour of the alternative and Factor 11 is found to be critical.

4.14 Factor 12 - There must be a learning-by-doing approach

In Section 3.3.12 the hypothesis was formed:

A learning whilst doing approach is critical for success

And a null hypothesis:

A learning-whilst-doing approach is not critical for success

The results from Fishers Exact Test are shown in Table 4.15 below.

Table 4.15 – Fishers test of factor twelve

	P-value:	0.355
	successes	failures
Factor Present	24	5
Not Present	1	1

The P value is > 0.1 therefore the Null Hypothesis cannot be rejected and the Factor is not found to be critical for Lean Construction to succeed.

4.15 Factor 13 Actions must be closed by the team

In Section 3.3.13 the hypothesis was formed:

Closing of actions by the improvement team is critical for success

And a null hypothesis:

Closing actions of by the improvement team is not critical for success

The results from a single tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.16 below.

Table 4.16 – Mann Whitney test for factor thirteen

Mann-Whitney test / Upper-tailed test:	
U	94.500
Expected value	75.000
Variance (U)	322.016
p-value (one-tailed)	0.078
alpha	0.1
The p-value is computed using an exact method	

XLSTAT Test output:

As the computed p-value is lower than the significance level alpha = 0.1, the null hypothesis is rejected in favour of the alternative. The risk to rejecting the null hypothesis when it is in fact true is lower than 7.76%.

With the null hypothesis rejected in favour of the alternative, the factor is found to be critical.

4.16 Factor 14 - People must be allowed enough time to spend on improvements

In Section 3.3.14 the hypothesis was formed:

Staff must be allowed to take time out to spend on the improvement efforts

And a null hypothesis:

Improvement efforts can succeed without taking time out away from work

74 per cent of respondents stated that success could only be achieved by taking time out in comparison to 26 per cent of respondents who believed the opposite to be true.

80 per cent of the former group stated that at least one day per week, or 20 per cent of a person's time was the minimum necessary to succeed.

An upper tailed one-sample Z test was used to test the null hypothesis that the theoretical mean would = 0.5, i.e. that there would be no significant difference between taking time out or not. The output from XLSTAT is shown in Table 4.17 below.

Table 4.17 – Z test results for factor fourteen

Theoretical mean: 0.5
Significance level (%): 1
Summary statistics:

Variable	Observations	with missing	without missing	Minimum	Maximum	Mean	Std. deviation
Var1	27	0	27	0.000	1.000	0.741	0.447

One-sample z-test / Upper-tailed test:

99% confidence interval on the mean:
] 0.541, +Inf [

Difference	0.241
z (Observed value)	2.801
z (Critical value)	2.326
p-value (one-tailed)	0.003
alpha	0.01

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is greater than 0.
As the computed p-value is lower than the significance level alpha=0.01, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 0.25%.

For certainty a non-parametric Binomial Sign test was also performed and returned a similar result with a *p* value of 0.0096. Based on this these tests and the mean of 74 per cent who said that taking time out was necessary the null hypothesis is rejected in favour of the alternative and the factor is found to be critical.

4.17 Factor 15 - A high level of communication between suppliers is key

In Section 3.3.15 the hypothesis was formed:

A high level of communication between suppliers is critical for success

And a null hypothesis:

A high level of communication between suppliers is not critical for success

The perceived level of collaboration was recorded for the successes and failures groups and compared. The results from a single tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.18 below.

Table 4.18 – Mann Whitney test for factor fifteen, part one

Mann-Whitney test / Upper-tailed test:	
U	38.000
Expected value	28.000
Variance (U)	78.052
p-value (one-tailed	0.172
alpha	0.1
The p-value is computed using an exact method	

XLSTAT Test output:

As the computed p-value is greater than the significance level alpha = 0.1, one cannot reject the null hypothesis. The risk to rejecting the null hypothesis when it is in fact true is lower than 17.16%

Respondents were then asked what effect the level of communication had on their efforts.

The results from an upper-tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.19 below.

Table 4.19 Mann Whitney test for factor fifteen part two

Mann-Whitney test / Two-tailed test:	
U	48.500
Expected value	28.000
Variance (U)	78.967
p-value (Two-tailed)	0.029
alpha	0.1
The p-value is computed using an exact method.	

XLSTAT Test output:

As the computed p-value is lower than the significance level alpha=0.1, one should reject the null hypothesis and accept the alternative. The risk to reject the null hypothesis while it is true is lower than 2.94%.

The results are:

- There was no significant difference in the level of communication between the failure and success groups.
- The effect the level of communication had was significantly higher in the success group.

4.18 Factor 16 - Must overcome silo thinking to succeed

In 3.3.16 the hypothesis was formed:

Failure to overcome silo thinking will cause a lean intervention to fail

And a null hypothesis:

Failure to overcome silo thinking will not cause a lean intervention to fail

The interviewees were asked to what extent silo thinking was present during their efforts to improve and this produced ordered category data. The results showed that there was a difference in the level of silo thinking between the success group and the failure group. The median and mode of the data in the success group was 3 – meaning "some silo thinking" and 4 within the failure group meaning "quite a lot". However the Mann Whitney test of the data reported that there was no significant difference between the two data sets and that the null hypothesis could not be rejected.

The interviewees were also asked what effect this had on their efforts and this produced ordered category data. No difference between the data sets was evident with the mode and median both 3 for each group with 3 relating to "had some effect". The Mann Whitney test confirmed no distinguishable difference could be found.

Two questions followed that produced narrative.

a) "What did you do about this?"

   and

b) "What happened as a result?"

A wide range of responses emerged from question a) with the most frequent response – 39 per cent, saying that they "talked it through with the other stakeholders". There was no apparent pattern to the other responses. A summary of coding results for the narrative data is shown in Table 4.20 below.

Table 4.20 Summary of narrative data for factor sixteen

Those that did nothing as there was no problem to begin with	17%
Those that perceived some level of silo thinking	83%
Those that took specific action to address silo thinking	57%
Those that felt things improved as a result of their actions	53%

The result was that whilst overcoming silo thinking appears to be a relevant issue as evidenced by the data above, it cannot be concluded from the data set obtained that it is critical.

4.19 Factor 17 - Relevant data must be available or created

In Section 3.4.1 the hypotheses was formed:

It is critical that relevant data are available or created

And a null hypothesis:

It is not critical that relevant data are available or created

When asked what sort of data would be useful for a lean intervention respondents replied with 9 different categories. The frequency of these is shown in Table 4.21 below.

Table 4.21 Respondents perception of data types that would be useful

Data Type	**No. Of Mentions**	**% Of Mentions**
Financial or cost data	10	27%
Current performance data	9	24%
Time related or programme	7	19%
No. of failures or delays and disruptions	6	16%
A competitors performance	1	3%
Don't know	1	3%
Managers opinions	1	3%
A process map	1	3%
Depends on the focus	1	3%

When asked whether any of this data was available or created for their improvement project 92 per cent of the successes but only 33 per cent of the failures said yes. The response data was input into Fishers Exact test and the result is shown in Table 4.22 below.

Table 4.22 Fishers test for factor seventeen

Fishers Exact Test		
	P-value:	0.006
	successes	failures
Factor Present	23	2
Not Present	2	4

The P value is < 0.1 therefore the Null Hypothesis is rejected in favour of the alternative. The factor is found to be critical for Lean Construction to succeed.

4.20 Factor 18 - More than one lean tool must be used to succeed

In Section 3.4.2 the hypothesis was formed:

More than one lean tool must be used for success in lean construction

And a null hypothesis:

Success in lean construction can be achieved using only one lean tool

The respondents were first asked if they had used more than one lean tool during their efforts to improve. All responded that they had, indicating no difference at all between the failure and success groups using the binary data. They were then asked how important it was that more than one tool was used with an ordered category question.

This question was not linked directly to either success or failure but rather represented the opinion of all 31 respondents. Responses to the question "In the context of your lean intervention/s, how important is it that more than one tool is used?" were categorised as *Unimportant, Of little Importance, Don't know, Important and Vital* and coded 1 to 5.

The results of 31 responses are shown in Table 4.23 below.

Table 4.23 Descriptive statistics for factor eighteen

Mode	4.0
Median	4.0
Mean	87%
% That said Important (4)	50%
% That said Vital (5)	47%

An upper tailed test for significance was carried out using a one-sample Wilcoxon signed rank test using the mid level hypothesis of 3 which equals "don't know" in the ordered rank question. The result was conclusive and returned a confidence level of more than 99 per cent. The output is shown in Table 4.24 below.

Table 4.24 Wilcoxon test for factor eighteen

The One-Sample Wilcoxon Signed-Rank Test				
Observations Processed:	30	**The Test Procedure**		
Hypothetical Value (mu0):	3			
Average of Input Data:	4.366	Test Statistic (S+):	442	
Median of Input Data:	4	Significance Level:	0.01	
Standard Deviation:	0.808			
		Right-Tailed Test (Normal Approximation)		
Nb. of Zero Differences:	0	Z Stat:	4.3	
Nb. of Tie Series:	2	Z Stat (Cont.-Adj.):	4.29	
Mean Nb. of Ties/Series:	15	Z Stat (Tie-Adjusted):	4.44	
		P-Value:	8.2×10^{-6}	
Rank Sum:	465	Critical Value:	2.326	
Rank Average:	15.5	Decision Rule:	Reject H0 if z > 2.326	
			H0 Must be Rejected	

Based on the data in Table 4.23 and the output in Table 4.24 the null hypothesis is rejected in favour of the alternative and factor 18 is found to be critical.

4.21 Factor 19 - A long term client relationship or work stream is critical for success

In Section 3.4.3 the hypothesis was formed:

A long-term client relationship or work-stream is critical for success

And a null hypothesis:

A long-term client relationship or work-stream is not critical for success

Respondents were asked if their improvement project concerned a long-term client or work-stream. The results from Fishers exact test are shown in Table 4.25 below.

Table 4.25 Fishers test for factor nineteen, part one

	P-value:	0.038
	successes	failures
Factor Present	23	3
Not Present	2	3

They were then asked what effect this had – either good or bad, with an ordered category question that would test the hypothesis:

A long-term client relationship or work stream will significantly influence the outcome of a lean intervention

And a null hypothesis:

A long-term client relationship or work stream will make no difference to the outcome of a lean intervention

The results from a one-tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.26 below.

Table 4.26 Mann Whitney test for factor nineteen, part two

Mann-Whitney test / Two-tailed test:	
U	110.500
Expected value	62.500
Variance (U)	287.141
p-value (Two-tailed)	0.004
alpha	0.1
The p-value is computed using an exact method.	

XLSTAT Test output:

As the computed p-value is lower than the significance level alpha = 0.1, the null hypothesis is rejected in favour of the alternative. The risk to rejecting the null hypothesis when it is in fact true is lower than 0.39%

Both the Fishers test and Mann Whitney test agree and the null hypotheses are rejected in favour of the alternatives, and Factor 19 is accepted as critical.

4.22 Factor 20 - There must be a high level of collaboration with sub-contractors

In Section 3.4.4 the hypothesis was formed:

A high level of sub-contract collaboration is critical for success

And a null hypothesis:

A high level of sub-contract collaboration is not critical for success

A two part question was formed: part one to establish the level of collaboration during the improvement efforts and part two to check what effect this had on the outcome. Both answers generated ordered category responses.

Part 1: The results from a one-tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.27 below.

Table 4.27 Mann Whitney test for factor twenty, part one

Mann-Whitney test / Upper-tailed test:	
U	45.500
Expected value	28.000
Variance (U)	71.647
p-value (one-tailed)	0.033
alpha	0.1
The p-value is computed using an exact method	

XLSTAT Test output for Part One:

As the computed p-value is lower than the significance level alpha = 0.1, the null hypothesis is rejected in favour of the alternative. The risk to rejecting the null hypothesis when it is in fact true is lower than 3.27%

Part 2: The results from a Two-tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.28 below.

Table 4.28 Mann Whitney test for factor twenty, part two

Mann-Whitney test / Two-tailed test:	
U	39.500
Expected value	28.000
Variance (U)	74.392
p-value (Two-tailed)	0.225
alpha	0.1
The p-value is computed using an exact method	

XLSTAT Test output for Part Two:

As the computed p-value is greater than the significance level alpha = 0.1, one cannot reject the null hypothesis in favour of the alternative. The risk to rejecting the null hypothesis when it is in fact true is lower than 22.55%

Result: The test for part 1 was significant at 96.7 per cent. There was definitely a higher level of supplier collaboration present in the successes than the failures. However, the experiences of the failures were evenly divided, with half saying that the level of collaboration was poor and that this had an adverse effect and half reporting that the level of collaboration was good and that this had a good effect. Whilst there was consensus that the level of collaboration was important and affected the outcome, half of the failures still failed despite reporting high supplier collaboration and the positive effects this brought.

Other characteristics of the data are shown in Table 4.29 below.

Table 4.29 Descriptive statistics of data for factor twenty

Level Of Supplier Collaboration	**Mean**	**% that said >4**	**Std. Dev.**
Successes Part 1 – From adversarial to highly collaborative	86%	93%	0.61
Failures Part 1 – From adversarial to highly collaborative	60%	50%	1.41
Successes Part 2 – Effect from very negative to very positive	86%	93%	0.61
Failures Part 2 – Effect from very negative to very positive	55%	50%	2.06

Although it is clear that for successful projects there was a stronger feeling that a high level of subcontractor collaboration was desirable than for projects that failed, the results are not sufficiently conclusive to validate the hypothesis.

4.23 Factor 21 - The right facilitator is critical

In Section 3.4.5 the hypothesis was formed:

The facilitator is critical to success

And a null hypothesis:

The facilitator is not critical to success

84 per cent of respondents had experience of more than one facilitator.

This question was not linked directly to either success or failure but rather represented the opinion of 26 respondents. The responses to the question “How important is the facilitator in ensuring success?” were categorised as *Unimportant, Of little Importance, Don’t know, Important and Vital* and coded 1 to 5.

Results of the responses are shown in Table 4.30 below.

Table 4.30 Descriptive statistics for factor twenty-one

Mode	5.0
Median	5.0
Mean	95%
% That said Important (4)	23%
% That said Vital (5)	77%

In addition, respondents were asked “If a contrast existed between trainers, what did the most successful one do that the other(s) didn’t?”

This produced narrative that was coded and the frequency of the keywords is shown below in Table 4.31 below.

Table 4.31 - What the most successful facilitators did

Facilitators Trait	No. Of Mentions	% Of Mentions
Specific construction knowledge and empathy with the team	8	31%
The ability to make it relevant	5	19%
Ability to keep the team on track	3	12%
Infectious enthusiasm	3	12%
Brought discipline	3	12%
A structured approach	1	4%
Ability to change pre-conceptions	1	4%
Made improvements "here and now"	1	4%
Knowledge and experience	1	4%
Achieved buy-in	1	4%

It can be observed from Table 4.31 above that the first four facilitator's traits listed accounted for a total of 73 per cent of all responses, whilst the remaining six responses account for only 27 Per cent.

An upper tailed test for significance was carried out using a one-sample Wilcoxon signed rank test using the mid level hypothesis of 3 which equates to "don't know" in the ordered rank question. The result was conclusive with a confidence level of 99 per cent. The output is shown in Table 4.32 below.

Table 4.32 Wilcoxon test for factor twenty-one

The One-Sample Wilcoxon Signed-Rank Test			
Observations Processed:	26	**The Test Procedure**	
Hypothetical Value (mu0):	3		
Average of Input Data:	4.76	Test Statistic (S+):	351
Median of Input Data:	5	Significance Level:	0.01
Standard Deviation:	0.429		
		Exact Proceedure Right-Tailed Test	
Nb. of Zero Differences:	0		
Nb. of Tie Series:	2		
Mean Nb. of Ties/Series:	13		
		P-Value:	0
Rank Sum:	351	Critical Value:	276
Rank Average:	13.5	Decision Rule:	Reject H0 if z > 276
		Final Decision	H0 Must be Rejected

Based on the data in Table 4.30 above and the output shown in Table 4.32, the null hypothesis is rejected in favour of the alternative and Factor 21 is found to be critical.

4.24 Factor 22 The age of the team is critical

In Section 3.4.6 the hypothesis was formed:

The age of the improvement team members is critical to success

And a null hypothesis:

The age of the improvement team members is not critical to success

This question was not linked directly to either success or failure but rather represented the opinion of the respondents. There were 30 responses to the question “Do you think the age of improvement team members is a critical factor for success?” Also “How old is too old, how young is too young, and why is this?”

Of the 30 responses 9 (30 per cent) thought age to be an issue with 21 (70 per cent) saying that it did not make any difference. The respective ages that the 30 per cent of respondents thought was too old or too young were >50 and <19 years old.

The 9 interviewees' reasons for age being an issue are shown in Table 4.33 below.

Table 4.33 Reasons for age being an issue

Reason given why age is an issue	**No. of mentions**
Those with less experience more accepting of change	1
Too set in their old ways	3
Pending retirement	2
A culture re-enforced over many years	1
More about attitude than age	2

An upper tailed one-sample Z test was used to test the null hypothesis that the theoretical mean would = 0.5, i.e. that age would make no difference. The output from XLSTAT is shown in Table 4.34 below.

Table 4.34 Z test for factor twenty-two

Theoretical mean: 0.5
Significance level (%): 1
Summary statistics:

Variable	Observations	with missing	without missin	Minimum	Maximum	Mean	Std. deviation
Var1	31	1	30	0.000	1.000	0.300	0.466

One-sample z-test / Upper-tailed test:

99% confidence interval on the mean:
] 0.102, +Inf [

Difference	-0.200
z (Observed v	-2.350
z (Critical val	2.326
p-value (one	0.991
alpha	0.01

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is greater than 0.
As the computed p-value is greater than the significance level alpha=0.01, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 99.06%.

For certainty a non-parametric Binomial Sign test was also performed and returned a similar result with a *p* value of 0.0147. Based on the mean of only 30 per cent agreeing that age is critical and the output from these tests, the null hypothesis is accepted and factor 22 is found not to be critical.

4.25 Factor 23 - There must be a no-blame culture to succeed

In 3.4.7 the hypothesis was formed:

There must be a no-blame culture to succeed

And a null hypothesis:

A no-blame culture is not necessary for success

The results from a single tailed Mann Whitney U test of the data using XLSTAT are shown in Table 4.35 below.

Table 4.35 Mann Whitney test for factor twenty-three

Mann-Whitney test / Lower-tailed test:	
U	28.000
Expected value	62.500
Variance (U)	299.569
p-value (one-tailed)	0.024
alpha	0.1
The p-value is computed using an exact method	

XLSTAT Test output:

As the computed *p*-value is lower than the significance level alpha = 0.1, the null hypothesis is rejected in favour of the alternative. The risk to rejecting the null hypothesis when it is in fact true is lower than 2.39%

With the null hypothesis rejected in favour of the alternative, the factor is accepted as critical.

4.26 Results Summary

Twenty-three factors were examined during the research project. Of these a total of thirteen were found to be critical. Nineteen Factors were identified in the literature, sixteen of these were tested and seven were found to be critical. Seven factors were identified as a result of the Pilot Study, seven were tested and five found to be critical.

A summary of all the results excluding narrative analysis appear in Table 4.37 below. An explanation of the colour coding can be found in Table 4.36 and justification of the categories is fully discussed in the next Chapter.

Table 4.36 - Key to Table 4.37

Y	Critical
I	Important
N	Not Critical

Table 4.37 Summary of results

CSF	No.	Test	Mode	Median	U Value	P Value	% that said >4	Mean	Conf. Level	Null Rejected Y/N	Criticality Status		
											Y	I	N
A crisis is necessary	1	Fishers				0.298			70.2%	N			N
There must be buy in from team	2	Mann Whitney 1 tail			118	0.013			98.7%	Y	Y		
There must be buy in from senior management	3	Mann Whitney 1 tail			116	0.07			93.0%	Y	Y		
Improvement efforts must be process, not result focused to succeed	4	Fishers				1			0%	N			N
Improvement goals must be set	5	Fishers				0.596			40.4%	N			N
The focus must be on the end user to succeed	6	Fishers				1			0%	N			N
The intervention must involve all stakeholders	7	Fishers				0.383			61.7%	N			N
Management must be capable	8	Fishers				0.034			96.6%	Y	Y		
Senior management must be directly involved	9	Fishers				0.067			93.3%	Y	Y		
Management must stay focused on the efforts	10	Mode, Median, Wilcoxon	5	5		5.87×10^{-7}	100%	97%	99.9%	Y	Y		
Appropriate training is critical for success in lean interventions	11	Mode, Median, Mean, Wilcoxon	4	4		1.31×10^{-5}	94%	85%	99.9%	Y	Y		
There must be a learning by doing approach	12	Fishers				0.355			64.5%	N			N
Actions must be closed by the team	13	Mann Whitney 1 tail			94.5	0.078			92.2%	Y	Y		
People must be allowed enough time to spend on improvements	14	Mean, Z test				0.003		74%	99.7%	N	Y		
A high level of communication between suppliers is key	15	Mann Whitney 1 tail			38	0.172			82.8%	N		I	
The effect of the level of communication	15a	Mann Whitney 2 tail			48.5	0.029			97.1%	Y			
The extent Silo thinking was present	16	Mode, Median, Mann Whitney 1 tail	4	4	44	0.866			13.4%	N			N
The effect silo thinking had on success	16a	Mann Whitney 1 tail	3	3	45	0.883			11.7%	N			N
Relevant data were available	17	Fishers				0.006			99.4%	Y	Y		
Need more than 1 lean tool	18	Mode, Median, Wilcoxon	4	4		8.2×10^{-6}	97%	87%	99.9%	Y	Y		
A long term client relationship or work stream is critical for success	19	Fishers				0.038			96.2%	Y	Y		
The effect of a long term client - good or bad	19a	Mann Whitney 2 tail			110.5	0.004			99.6%	Y			
There must be a high level of collaboration with sub-contractors	20	Mann Whitney 1 tail			45.5	0.033			96.7%	Y		I	
Effect of the level collaboration between suppliers	20a	Mann Whitney 2 tail			39.5	0.225			77.5%	N			
The right facilitator is critical	21	Mode, Median, Mean, Wilcoxon	5	5		0	100%	95%	100%	Y	Y		
Age is an issue	22	Mean, Z test	0	0		0.991		30%	1%	N			N
Must be a no blame culture	23	Mann Whitney 1 tail			28	0.024			98%	Y	Y		

CHAPTER 5 - DISCUSSION

5.1 Summary Of Key Findings

Hypotheses for 23 potential critical success factors were formed and tested for significance. Thirteen were found to be significant as shown in Table 5.1 below and eight not significant as shown in Table 5.2. In addition, a further two factors returned conflicting results. These are discussed in Section 5.6.

Table 5.1 Hypotheses that tested as significant

	Critical success factors - hypotheses that tested as significant	
No.	**Hypothesis**	**Confidence Level**
21	*The facilitator is critical to success*	>99%
18	*More than one lean tool must be used for success in lean construction*	>99%
10	*It is critical that management stays focused on the efforts to improve*	>99%
17	*It is critical that relevant data are available or created*	>99%
11	*Training in lean techniques is critical*	>99%
14	*Staff must be allowed to take time out to spend on the improvement efforts*	>99%
2	*Buy-in from the improvement team is critical for success*	99%
19	*A long-term client relationship or work stream is critical for success*	>95%
8	*Capability of management is critical for success of a lean intervention*	>95%
23	*There must be a no-blame culture to succeed*	>95%
3	*Buy-in from senior management is critical for success*	>90%
9	*Direct senior management involvement is critical for a lean intervention to succeed*	>90%
13	*Closing of actions by the improvement team is critical for success*	>90%

Table 5.2 – Hypotheses that tested as not significant

Critical success factors - hypotheses that tested as not significant		
No.	**Hypothesis**	**Confidence Level**
4	*Lean Construction must be process focused to succeed*	<90%
5	*It is critical that improvement goals are set*	<90%
6	*End user focus is necessary to succeed*	<90%
7	*The intervention must involve all stakeholders to succeed*	<90%
12	*A learning whilst doing approach is critical for success*	<90%
16	*Failure to overcome silo thinking will cause a lean intervention to fail*	<90%
22	*The age of the improvement team members is critical to success*	<90%
1	*A crisis is necessary for lean construction to succeed*	<90%

The two hypotheses that returned conflicting results were:

- CSF 15 - *A high level of communication between suppliers is critical for success*
- CSF 20 - *A high level of sub-contract collaboration is critical for success*

5.1.1 Successful versus failed interventions

The first step in the interview process was to establish whether the respondent perceived the lean intervention to be a success or a failure, as this was not known beforehand. Twenty five out of 31 respondents said the efforts were successful. The statistical probability of 25 out of 31 interventions being successful by chance is < 1%. In other words, it is highly likely that lean thinking works in the context of construction.

5.2 Descriptors Of Success

In Section 4.2 descriptors of success were reported and the percentage of the 31 respondents citing the top four was:

- On Time or Saved Time – 42 per cent.
- Cost Savings – 35 per cent.
- Some Other *Measurable* result – 23 per cent.
- People Engagement – 19 per cent.

Typical quantifiable measures of cost or time saved were most often quoted. However, the third and fourth largest categories of response are more interesting as they were different to the usual business measurement categories of quality, cost and delivery. The third largest response suggests that a measurable outcome is required in order to judge success. In other words, the concern was not so much that time or money could be saved but that something was measureable. This possibly links with CSF No. 17 concerning the use of data. The fourth largest category is perhaps even more interesting when looking back at the raw data. Of the six failures, three respondents mentioned lack of people engagement as the reason they deemed the effort to have failed. This may link to CSFs 2 and 3 that are concerned with the concept of getting buy-in. In short, these success descriptors support the findings that CSFs 2- buy-in from the team, 3- buy-in from management and 17 – relevant data available are indeed critical.

5.3 Cause And Effect Links Between Critical Success Factors

If it is considered that some of the factors tested may be related, then summarising possible links into a form of cause and effect would be helpful in understanding the relationships. This is considered in Table 5.3 below which shows the potential links between the statistically significant factors.

Table 5.3 Cause and effect links between critical success factors- Orange highlights signify highest counts and yellow the lowest counts. See page 133 for in text explanation

Cause & Effect Links between Critical Success Factors															
No.	CSF	2	3	8	9	10	11	13	14	17	18	19	21	23	
	Effect / Cause	Buy in from team	Buy in from senior management	Management must be capable	Senior management directly involved	Management must stay focused	Appropriate training	Actions must be closed by the team	People allowed to spend enough time	Relevant data were available	More than 1 lean tool	A long term client or work stream	The right facilitator	Must be a no blame culture	count of effects
2	Buy in from team		X					X							2
3	Buy in from senior management	X			X	X	X	X	X	X				X	8
8	Management must be capable	X			X	X	X	X	X	X	X	X	X	X	11
9	Senior management directly involved	X	X			X		X	X	X		X		X	8
10	Management must stay focused	X	X		X			X	X	X					6
11	Appropriate training	X	X	X	X			X		X	X			X	8
13	Actions must be closed by the team	X	X			X				X					4
14	People allowed to spend enough time	X						X		X	X			X	5
17	Relevant data were available	X	X			X		X							4
18	More than 1 lean tool	X	X												2
19	A long term client or work stream	X	X		X	X	X	X	X	X					8
21	The right facilitator	X	X	X	X	X	X	X	X	X	X			X	11
23	Must be a no blame culture	X	X							X					3
	count of causes	12	10	2	6	7	4	10	6	10	4	2	1	6	

In Table 5.3, existences of potential interrelationships are considered. Critical factors are shown in the second column as possible causes and in the second row as possible effects. The X's on the matrix represent potential links between factors. For example, when looking at the cause "Buy-in from the team" this shows that if buy-in from the team was present then this might possibly influence factors three and thirteen.

The placement of each "X" on the matrix was chosen by considering each success factor in turn as a potential "cause", and how this cause might positively influence the other factors as a possible effect. By way of an example the logic followed in the placement of X's for factor 9 – senior management involvement is explained in Table 5.4 below.

For interests sake a count has been made of the number of causes that are possibly linked to each factor as well as the number of effects. The highest of these are highlighted in orange (see Table 5.3 above). It can be seen that Factor 2 - *buy-in from the team*, has perhaps the greatest ability to be affected by other factors showing a count of 12. Factor 8 - *capability of management*, has perhaps the greatest ability to influence the other factors, along with the Factor 21 - *right facilitator*, with both having counts of 11. It may be of interest to note that the factors that have the lowest counts of causes, highlighted in yellow – capability of management (Factor 8), a long term client or work-stream (Factor 19) and the right facilitator (Factor 21), also have the highest counts of effects, suggesting that these three factors possess the greatest ability to affect the other factors. Building on this logic, it can be argued that the factors that have the greatest effect but for which the number of causes is the smallest should be the first to be considered. This is because there are fewer actions to take or conditions to satisfy in order to have a large effect. Using this logic, the factors are listed in the potential order of importance in Table 5.5, which shows each factor ranked by its "influence factor", the number of effects divided by the number of causes. Thus, the influence factors represent the effect per unit cause, and their rank order indicates the causes that have the greatest effect.

Although the data captured does not permit a full analysis of these inter-relationships or tests of all the potential new hypotheses that might emerge, this might be a worthy subject of further research.

Table 5.4 Explanation of cause and effect matrix

Factor No.	Factor Name as “Effect”	Senior Management Directly Involved - reason for X placement
2	Buy-in from team	It is probable that senior management being directly involved would engender buy-in from the team
3	Buy-in from senior management	If senior management were directly involved it is likely they would also be “bought–in”
8	Management must be capable	Being directly involved would not necessarily mean they are capable
10	Management must stay focused	Being directly involved would likely help them stay focused
11	Appropriate training	Being directly involved would not necessarily cause training to happen
13	Actions closed by the team	Being directly involved would encourage the team to close their actions
14	People allowed enough time	It is considered that being directly involved would also mean that they would give their people the necessary time for improvements as they would understand first hand what was required
17	Relevant data available	Senior management would be more able to access relevant company data
18	More than one lean tool	Direct involvement of senior management would not necessarily lead to the use of more than one tool
19	A long term client or work-stream	Direct involvement in lean improvements by senior management would likely have a positive effect on repeat business and customer retention
21	The right facilitator	Direct involvement of management would not necessarily cause the right facilitator – there might be no facilitator at all
23	Must be a no-blame culture	The direct involvement of senior management, working on process improvement alongside their juniors would likely help to combat any blame culture present

Table 5.5 Factors ranked by potential to influence

Factor	count of causes	count of effects	rank	Influence factor
The right facilitator	1	11	1	11.000
Management must be capable	2	11	2	5.500
A long term client or work stream	2	8	3	4.000
Appropriate training	4	8	4	2.000
Senior management directly involved	6	8	5	1.333
Management must stay focused	7	6	6	0.857
People allowed to spend enough time	6	5	7	0.833
Buy in from senior management	10	8	8	0.800
Must be a no blame culture	6	3	9	0.500
More than 1 lean tool	4	2		0.500
Actions must be closed by the team	10	4	10	0.400
Relevant data available	10	4		0.400
Buy in from team	12	2	11	0.167

5.4 Statistically Significant Success Factors And Interdependencies

In this section each of the significant factors are discussed in turn and potential interdependencies are considered.

5.4.1 CSF 2 – There must be buy-in from the improvement team

The results in Section 4.4 are fairly conclusive, showing that there was a significant difference in the level of buy-in between the successful interventions and the failures.

Further, this factor is believed to be critical. There was unfortunately no direct discussion with the respondents in terms of what caused the presence or absence of buy-in and this would have certainly been useful in hindsight. This factor appears the most frequently linked to other factors as shown in Table 5.3 above.

It is out-with the scope of this research to consider all the potential ways to achieve buy-in. However, some appear to be linked to other factors and these links are considered in Table 5.6 below. It is also the case that buy-in may be simultaneously classed as an outcome and a cause of success.

5.4.2 CSF 3 - There must be buy-in from senior management

The results are again fairly conclusive that this factor is critical. When comparing the failure group to the success group, the perceived level of management buy-in was approximately 40 per cent higher in successful interventions. The Mann Whitney test rejected the null hypothesis with a confidence level of 93 per cent. Looking back at the literature, the Asda case study presented by Beer (2003) is of particular interest as it shows a strategic effort to obtain buy-in from management that was successful. A key component of this effort was a type of management assessment called a “driving test” which checked whether store managers’ skills in leading the change process were aligned with the intended changes. The approach adopted by Asda seems harsh as they replaced 60 per cent of store managers if they were either unable or unwilling to adopt the requirements necessary to pass their “driving test”. This perhaps raises more questions for the construction sector than it answers. Would it be possible to conceive a “model project” road test for construction managers similar to Asda’s? If so, would business leaders be prepared to “get buy-in” even if it meant losing some of their people? Similar to the other factors already discussed, it seems likely that the level of buy-in from management is linked to, and likely to influence, some of the other factors.

Table 5.6 - The relationship between buy-in and other factors

The effect of other CSFs on buy-in from the team	
CSF	**Reason for link to buy-in**
3. Buy-in from management	It is hard to see why the improvement team would buy-in to the process if management have not.
8. Capability of management	It will be discussed in Section 5.13 that a key required capability is "the ability to get buy–in"
9. Direct involvement of management	If senior management are directly taking part with the team this might elevate the importance of the project. When necessary, decisions could be taken sooner that could possibly empower and further motivate the team.
10. Management must stay focused	If management does not stay focused the improvement team might be expected to follow suit.
11. Appropriate training	Training the team might show commitment from management and if techniques are learnt that make success easier then this might enhance levels of buy-in
13. Actions closed	If actions were closed in a timely fashion by the team then progress might be more likely, leading to a sense of achievement and therefore helping with buy-in
14. People allowed to spend enough time	This might demonstrate management commitment and have an effect on the level of buy-in
17. Relevant data available	If clear data rather than opinion were used for improvement efforts, consensus for what to do might be more easily achieved. It could be easier to get people "on-board" by use of relevant data to make the argument.
18. More than 1 lean tool	If the team were able to use more than one lean tool it would suggest a higher level of proficiency and therefore more buy-in by default
19. A long term client	A long term client could provide motivation that would assist in getting buy-in
21. The right facilitator	A skilled facilitator would likely know how to create empathy with the team – specific knowledge of their processes might help engender buy-in
23. A no-blame culture	Teams might resist taking any risks if a blame culture exists. The concept of risk taking is built into the Plan, Do, Check, Act cycle, which requires experimentation, albeit on a small scale.

5.4.3 CSF 8 - Management must be capable

Beer (2003) asserts that the capability of management is essential, but does not offer a practical description of capability. However, clues can be found within the Asda case study that assessed manager skills in leading change, and it is therefore taken for granted that Beer means capability in the context of leading change.

In this research the perceptions of management capability were measured rather than capability itself. This introduced both strength and weakness to the methods used: Strength because perceptions are taken to be important, and weakness due to the lack of a definition of capability. Instead of trying to assess capability directly, respondents were first asked what management skills and attributes were essential for a lean intervention. After giving their description they were then asked whether these skills or attributes were present within their own intervention efforts.

The results show that the perception that management was capable was present in all of the successes but only one third of the failures. Fishers Exact test returned a *p* value of 0.034, i.e. the results were statistically significant at a confidence level of 97 per cent.

Perhaps more interesting are the descriptions of capability, given that these were now firmly within the context of managements role within the deployment of lean thinking and perhaps provide more accurate descriptions of capability than those offered by Beer (2003).

A full list of descriptions appearing in Table 4.8 on page 101, shows that the top two skills or attributes quoted were “the ability to get buy-in” and “fosters teamwork”. Some of the other descriptors such as the “ability to involve everybody” or “able to motivate” also suggest the main skill a manager needs is the ability to get buy-in.

In summary it is felt that useful descriptions of capability of management have been provided by the data and that in the context noted capability of management appears to be critical.

5.4.4 CSF 9 - Senior management must be directly involved

Senior managers were directly involved in 16 of the 25 successes and in only 1 of the 6 failures. Fishers test returned a p value of 0.067 or a confidence level of 93 per cent. In addition, when asked what sort of things management actually did the top three categories were "provided visible support", "joined in the activity" and "initiated the improvements."

Direct involvement of senior management was regarded as a critical enabler by Bateman (2001). Spear (2004) also highlights this point. In discussing leadership training at Toyota, Spear describes in detail how senior managers personally led improvements. Liker (2004) describes the Toyota principle of Genchi Genbutsu, which means, "go see for yourself."

Direct involvement by senior management, by displaying commitment to the improvement team may help to provide motivation. It may also be the case that decisions regarding improvements could be taken much sooner and that this would help maintain momentum.

5.4.5 CSF 10 - Management must stay focused on the efforts

Whilst not linked to particular successes or failures, 16 per cent of respondents considered this factor important and 84 per cent considered it vital. Bateman (2001) provides some guidance on how maintaining focus can be achieved:

- Reviewing progress.

- Reviewing performance monitors.
- Reviewing suggestions.
- Dealing with issues that might arise from new ways of working.
- Protecting improvement activities from external influence.

Beer also discusses "The capacity of the senior team to follow up their initial commitment……" (Beer 2003: 627).

The research findings agree with the literature that this factor is critical for success.

5.4.6 CSF 11 - Appropriate training is critical for success in lean interventions

This factor was not linked to success or failure but represented the opinion of all 31 respondents. Overall, 52 per cent said it was important and 42 per cent said it was vital.

There is a long history of training going hand in hand with efforts to improve. Examples can be found throughout the development of lean thinking from Frederick Taylor to Training Within Industry (Deming 1986; Gaupp and Wrona 2006; Gilbreth 1948; Ohno 1988; Taylor 1911). Within the construction specific literature, improvement skills are mentioned as critical by Mitropoulos and Howell (2001) and also by Brady, Tzzortopoulos and Rooke (2011).

One voice against training in lean is John Seddon, who asserts that it is not necessary (Seddon 2003). In opposition to this, however, the vast majority of the literature together with the data obtained from this research provides for a convincing case in favour of training and this factor is perceived to be critical.

5.4.7 CSF 13 - Actions must be closed by the team

A comparison was made between the success and failure groups regarding the extent to which actions were closed. A Mann Whitney U test returned a p value of 0.078 or an approximate 92 per cent confidence level.

Bateman (2001) stated that a key differentiating factor for the most successful improvement teams was that they “closed out technical issues”, i.e. they closed outstanding actions.

The use of action lists during an improvement effort allows a team to formally record what has been agreed and track their progress. It would make sense that this procedure would be helpful given the wider task in hand to improve performance in a structured manner. The core philosophy of any modern improvement methodology appears to sit within the “Plan-Do-Check-Act” (PDCA) cycle and follows the scientific method (Deming 1986). If this is true then forming and reviewing actions as a team would be an entirely consistent methodology. Thinking more broadly, the process of reviewing actions could serve to increase motivation (buy–in). If an action was not closed on time it could create peer pressure and if completed on time would allow a sense of achievement. Both of these are in the very top league of motivators according to Kohn (1999): working as part of a team and a sense of achievement. A study by Fishbach, Koo and Finkelstein (2014) discusses this at length and concludes that the action list review process has significant consequences for the strength of motivation.

The research findings here agree with the literature and this factor is considered to be critical.

5.4.8 CSF 14 - People must be allowed to spend enough time on improvements

This question was not linked to failure or success, but represents the opinion of all the respondents. Overall, 74 per cent said that they felt success could only be achieved by taking time out. Of these, 80 per cent felt that one day per week was the minimum time out necessary to succeed.

If people are allowed to spend enough time, or put another way – allowed to take time away from their usual job to work on improvements, this might provide tangible evidence of management buy-in and could act as a motivator, fostering team buy-in. Spending appropriate time will more likely yield earlier results and so foster a sense of achievement, creating a virtuous cycle. This research concurs with Mitropoulos and Howell's view that time spent will likely directly affect operational improvements (Mitropoulos and Howell 2001). As such, the factor is maintained as critical for success.

5.4.9 CSF 17 - Relevant data must be available or created

Relevant data were available or created in 23 out of 25 successes and in 2 out of 6 failures. Fishers test returned a p value of 0.006, suggesting the result is significant at a confidence level of over 99 per cent. Types of data most commonly mentioned by respondents related to cost or time.

This factor emerged from the pilot study after numerous mentions by the pilot group. Within the literature on improvement methods, there is extensive instruction available on data manipulation and analysis (Deming 1986; Juran 2000; Pyzdek 2003). However, there is little guidance on how to capture appropriate data in the first place apart from Horner and Duff's guidance on using site diaries (Horner and Duff 2001).

Deming was clear in his instruction that management constantly makes mistakes due to a lack of understanding in the use of data, but again assumes that the data exists in the first place. In 1999, the construction sector began to collect key performance indicators (KPI's) using project performance data, as a direct result of the Egan Report (Egan 1998). However, such data are at the highest level in the hierarchy of data collection and do not provide any useful information regarding what to do to improve. For example, knowing that 45 per cent of projects finish late does not provide any clues as to why they were late. A core principle of lean thinking is problem solving using root cause analysis (Bicheno 2000; Liker 2004). Relevant data in the context of lean thinking would allow root cause analysis to take place. In other words, if 45 per cent of projects finished late then the most frequent cause of lateness must be identified. At this second level it may still not be clear what to do, e.g. if the second level reason for late projects was poor sub-contract performance it would still be necessary to examine what caused the poor performance. If this was, for example, found to be late information then the reasons for late information would need to be captured and this process of root cause identification continued until a practical response to the problem can be found. The use of data might also help to achieve buy-in at all levels of an organisation if it were presented appropriately.

It is concluded here that this factor does appear to be critical with the caveat that "relevant data" means data that is able to guide improvement efforts and not just benchmark performance.

5.4.10 CSF 18 - More than one lean tool must be used to succeed

All of the respondents had experience of more than one lean tool and all thought that this was important or vital. The result in favour of the hypothesis was significant at 99 per cent. This factor emerged from the pilot study after respondents repeatedly mentioned using a range of tools and techniques as important.

There are many books on lean tools and techniques in one form or another as applied to manufacturing, and a few in the context of construction. Different camps have emerged that rival each other, including lean, six-sigma, theory of constraints and total quality management. These improvement philosophies use many of the same tools and techniques, and do appear pre-occupied with the use of tools (Juran 2000). However lean is actually not about tools according to Bicheno (2000).

It is considered here that if only one lean tool is used then the focus might be on the tool and not the problem. Conversely, using more than one lean tool might evidence more focus on the problem than the tools. If this were true then it would make sense that using more than one lean tool would be critical for success, even though in reality the issue is not about tools at all.

5.4.11 CSF 19 - A long term client relationship or work stream is critical for success

A long-term client or work-stream was present in 23 out of 25 successes and in 3 out of 6 failures. A comparison was made between the success and failure groups using Fishers test and the null hypothesis was rejected with a confidence level of over 95 per cent. In addition, the effect (good or bad) of a long-term client was tested and again was found significant at over 99 per cent.

This factor emerged from the pilot study, but there are also good examples from the literature in lean manufacturing where efforts are made to form long-term relationships with suppliers (Liker 2004; Womack and Jones 1996).

Deming (1986) recommended long term relationships and single suppliers per item and makes the argument that using two suppliers will lead to twice as many problems than with one.

In the Toyota Production System Ohno (1988) talks about three kinds of waste, Mura, Muri and Muda. These translate into unevenness, overburden and non-value adding work. The first two are very relevant in any discussion surrounding lean thinking and supply chains. Unevenness in construction equates to feast and famine of workloads and a lack of predictability concerning the forward order book. This in turn means a natural reluctance to employ sufficient staff to cope with peaks in demand, thus leading to overburden. Within a long-term work-stream or client relationship, efforts can be made to level the workload or at least to gain more predictability or early view of future orders. This is a key enabler for lean. The literature, pilot study and main study concur that this factor is critical.

5.4.12 CSF 21 - The right facilitator is critical

26 of the 31 respondents had experience of more than one lean construction facilitator. All 26 said that they felt that the right facilitator was important or vital, with 77 per cent stating that it was vital.

The data were subjected to a hypothesis test and the null hypothesis was rejected with a confidence level of 99 per cent.

It may be of interest to note that when asked to compare facilitators and comment on what the most successful one did, the most frequent comments were “specific construction knowledge” and “the ability to make it relevant”. It is also considered here that a good facilitator would be able to influence some of the other success factors by virtue of their skill and experience. For example, an experienced facilitator might be able to help with buy-in from the team and management, help the team to focus on process not results, help management stay focused, assist with supplier communication and collaboration and provide guidance on data collection and analysis.

The results are quite conclusive and also make sense in the context of the other success factors. The “right” facilitator would appear to be critical.

5.4.13 CSF 23 - There must be a no-blame culture to succeed

The perception of the level of blame culture present was compared between the failure and success groups. It appears that the level of blame culture was higher in the failure group. A hypothesis test confirmed that the difference was statistically significant at over 95 per cent.

Whilst this factor emerged from the pilot study examples can be found in the literature that supports the hypothesis that this is critical. A core philosophy of virtually all the improvement methodologies is the scientific method of learning. This manifests itself in the Shewhart cycle of Plan, Do, Study, Act, in six sigma’s Define, Measure, Analyse, Improve, Control and in the theory of constraints as the five focusing steps of POOGI – (Process Of On-going Improvement) (Cox and Schleier 2010; Pyzdek 2003; Deming 1986). The point is that all of these core methods require risk taking albeit on a small scale. It is considered that the willingness of the improvement team to take risks might reduce proportionately to an increased level of blame. This then might hamper continuous improvement. It is concluded that CSF 23 is critical.

5.5 Success Factors That Tested As Not Significant And Interdependencies

In this section factors that tested at <90 per cent confidence level are reviewed and interdependencies with other factors considered.

5.5.1 CSF 1 - There must be a crisis

It was established that the perception of crisis was present in 8 of the 25 successes and none of the failures. From a statistical standpoint using Fishers Exact test this was not conclusive enough to be deemed critical: returning a *p* value of 0.298 or an approximate probability of 70 per cent. Clearly, success can be gained without the pressure of a perceived crisis. This is contrary to existing literature that not only states that a crisis is helpful or necessary but recommends that somehow management should go to the trouble of creating one if it does not already exist (Wolstenholme 2009; Womack and Jones 1996). However, it is interesting to note and cannot be ignored that the perception of crisis was absent in all of the failures. It would make sense that the presence of a crisis could serve to motivate people to action and galvanise the efforts of an organisation, but only provided that the people in question actually cared about their organisation – if not, the presence of crisis might just prompt them to move on. This factor also appears to be possibly linked to the concepts explored in CSFs 2 and 3, namely buy-in.

The presence or creation of a crisis under certain circumstances might possibly provide a method for achieving buy-in. It is not the only method, however, and may not always work, or indeed be necessary at all, as evidenced by this research. It may be interesting to consider that the automotive sector reacted positively to the crisis caused by the publication of benchmark data in the “Machine That Changed The World” (Womack, Jones and Roos 1990). Since 1999, UK construction benchmark data has been collected by Constructing Excellence (Glenigan 2014), but despite the benchmark data generally reporting poor performance, by showing for example that in 2014 that there was only a 50 per cent chance of a project finishing on time, the industry still appears to be struggling to improve. More recent research by Leong, Ward and Koskela (2015) suggests that specific benchmarking using a lean index metric may help motivate the sector. It is concluded here that this factor is not universally critical although may be useful under certain circumstances. Anecdotal evidence and the contribution of this research suggest that the construction sector does not appear to react to crisis in the same way as other industry sectors.

5.5.2 CSF 4 – Improvement efforts must be process not result focused

No significant difference was found between the success and failure groups regarding the extent to which this factor was present. Furthermore, within the success group, 9 out of the 25 interviewees declared that they were focused on results rather than process and within the failure group 4 out of 6 said they were focused on process rather than results.

This result is not in keeping with the lean philosophy to concentrate on the process that produced the results rather than the results themselves (Bicheno 2000). A particularly good construction explanation of this appears in Mitropoulos and Howell's (2001) work shown in Table 2.5 on page 44.

Using a similar argument it could also be the case that in order to achieve the goal of "zero defects" on a project, significant extra time might be added to the end of the project to allow a snagging/de-snagging process to take place. The goal would be achieved as far as the customer is concerned, as the defects would not appear at the end, but the cost of rework would remain. Application of a lean philosophy would require a change of focus to establish ways to avoid making mistakes in the first place. In the former circumstance there is only an illusion of success, it does not use a true lean measure of 100 per cent right first time.

A possible explanation for this contradictory result is that the reason for beginning the improvement could well be result-focused. However, in terms of the implementation of the improvement efforts, it is possible that the successes actually did focus on process during the efforts.

Returning to the interview question it appears that this could be the case. The interview question took the following form:

> "When deciding the focus or project scope, which of the two following statements more closely fits what you did" (Must be process focussed rather than results focused).
>
> a. "The aim is to simplify and reduce the number of steps required and remove waste, and generally improve the process, which we have faith will lead to a better result."
>
> b. "The aim is to improve performance from a to b with 'a" being the lead time or cost or other tangible measurable result."

Therefore it is considered here that whilst responding with "b" as an initial project scope the real answer could easily have been "a" once the improvement efforts got going.

This appears to be an error in methodology and so this factor is now considered neither proven not disproven to be critical. It may also be the case that Mitropoulos and Howell's (2001) use of the word "focus" might have been better framed as "orientation" or even better expressed in terms of "what's and how's". For example, *What* = zero defects at Practical Completion and *How* = avoid rework by using small batch size, mistake-proofing, sequential inspection etc.

5.5.3 CSF 5 - Improvement goals must be set

Improvement goals were set in 20 out of 25 successes but also in 4 out of 6 failures. Fishers test returned a p value of 0.59 so criticality could not be confirmed from the data.

Goals were set either by the team, management or the client. No correlation could be found between who set the goals and success or failure.

There is a school of thought that holds goal setting to be destructive to performance improvement. Deming (1994) in particular was completely against the idea of using any numeric target as a focus for improvement, holding the view that the numeric target would somehow be achieved but the actual performance would worsen. He even refused to give grades to his students saying they would either "pass" or need to study some more until such time as they could "pass". He maintained that people have a habit of fudging the figures to meet the target, so targets are met but nothing changes. Deming called this "Management by objective". He later amended this assertion slightly to decry "management by objective – without means", meaning that if an objective or numeric target is stated, clear means of how this would be achieved must also be provided. To put this in a more specific context, the goals referred to here are numeric or quantifiable goals and not general goals to improve.

Given that 20 out of 25 successes set goals, one could be forgiven for concluding that the factor is critical. However, when also considering that 4 out of 6 failures also set goals, it would appear that this is not the most important consideration when embarking on a lean journey. All the available evidence suggests that this factor is not critical.

5.5.4 CSF 6 - The focus must be on the end user to succeed

Only 5 out of 25 successes and one of the failures focused on the end user. It would appear that success in lean construction can occur without this focus. This is contrary to the literature (Womack and Jones 1996). However, in a construction context it is likely that the focus would be on the client rather than the end user. Within the automotive industry and other manufacturing sectors end user focus is vital to ensure sales, evidenced by the success of Lexus and Toyota: Japanese design engineers went to America to live and observe the American peoples needs and wants for cars; consequently they designed in line with these observations (Womack and Jones 1996). In construction, however, the actual stakeholder that must be satisfied is very often not the end user but the client. It may well be the case, indeed it probably is the case that exceptions will exist. Consider for example a developer who is also a house builder: sales of houses to end users would likely be critical. It is concluded that whilst this may be important in some circumstances, it is not universally critical.

5.5.5 CSF 7 - The intervention must involve all stakeholders

The perception of the respondents was that all stakeholders were present in ten of the successful interventions and one failure. There were missing stakeholders in fifteen of the successes and five of the failures. Thirteen of those who said that there were missing stakeholders said this had “no effect”. It is possible that this factor could have a significant effect, as it was absent in five out of six failures. As it was also absent in fifteen of twenty-five successes, however, it seems reasonable to conclude that it is not critical. Of the comments made by respondents when asked what effect missing stakeholders had the most interesting was “Missing client was a barrier to getting buy–in”. This response occurred 4 times and again points toward the importance of buy-in. Looking back to the literature AlSehaimi, Tzzortopoulos and Koskela (2009) state that the involvement of all stakeholders is critical after using a ten-question survey of people working on two projects that were attempting to use the Last Planner System. The Last Planner interventions on both projects were deemed successful. As no comparison between failures or successes was carried out it is considered that the results of the current research are perhaps more robust.

5.5.6 CSF 12 - There must be a learning by doing approach

A learning whilst doing approach was taken in 24 out of 25 successes and in 5 out of 6 failures. The difference between the two groups was not found to be statistically significant. Fishers test returned a p value of 0.355 and so the null hypothesis could not be rejected.

Whilst debated, the origins of this training philosophy have been credited to the Chinese philosopher Confucius and summarised as: *"I hear and forget, I see and remember, I do and I understand"* (Vaillancourt 2009: 1). A learning by doing approach was central to the lean training methodology taught by the SMMT Industry forum to the UK automotive sector and adopted by a further 14 industry sectors including construction (DTI 2006). In addition, the task based approach recommended by Beer (2003) and the evidence from the Training Within Industry approach (Gaupp and Wrona, 2006) suggests that the learning whilst doing approach is a very good idea.

It is therefore interesting that the evidence gained in this research does not support the hypothesis that this is critical to success. Given this discrepancy, it is considered that whilst this approach is in all probability a very good idea (as suggested by the literature), when embarking on a lean intervention it perhaps should not be the prime concern but rather a "nice to have".

5.5.7 CSF 16 - Must overcome silo thinking to succeed

A comparison of the perceived level of silo thinking between the failure and success groups was made and although the level of silo thinking was slightly higher in the failure group no statistical difference was determined. Within the narrative data, it appears that in 25 per cent of instances the perceived level of silo thinking naturally improved as a result of undertaking the intervention. Comments such as “It just went away” and “resolved naturally due to teamwork” were found. Of the 83 per cent that said there was some level of silo thinking present, 48 per cent took direct action to improve this.

It is perhaps easier to understand silo thinking with reference to its opposite, systems thinking. Much has been written about the importance of systems thinking (Deming 1994; Seddon 2003; Senge 1990). Seddon in particular asserts that it is the only thing that matters. However no study or literature was found that could provide any correlation between the level of silo thinking or systems thinking and improvement effort success.

Within this study the evidence suggests that silo thinking was a concern to many of the respondents, 40 per cent of which were prompted to take direct action due to its presence. However it appears that it did not cause serious problems and was relatively easy to overcome. This then should perhaps not be a prime concern when planning a lean intervention, as it seems likely to resolve itself as a positive side effect of the improvement efforts. Despite the literature on the subject, it cannot be concluded from this study that the factor is critical.

5.5.8 CSF 22 - The age of the team is critical

The results returned a verdict that age does not matter. Only 30 per cent or nine respondents thought age to be an issue and when asked to expand on this two said it was actually more about attitude than age, two said that pending retirement was the issue and one said that the less experienced people (but not necessarily younger) were more accepting of change. That leaves only four or 19 per cent that actually thought age was an issue.

It may be interesting to consider the general effect of life events on improvement team participants. Pending retirement is potentially a life changing event and it may be the case that a person with this in mind may find it difficult to get enthused by the latest company improvement project. It is also possible that a younger person might feel the same if they were considering changing job, moving house or getting married or some other significant life event. In other words retirement could be classed as any other major life event and not be related to age in the context of improvement efforts.

5.6 Factors That Returned Conflicting Results

5.6.1 CSF 15 - A high level of communication between suppliers is key

A comparison of the level of communication present was made between the success group and the failure group using a Mann Whitney U test. Less data was available for analysis as only 18 of the 31 respondents said their improvement efforts involved suppliers or sub-contractors. There were 4 failures and 14 successes.

The Mann Whitney test reported no significant difference in the level of communication between the failure and success groups, but the effect the level of communication had was significantly higher in the success group.

The lean construction literature that relates to this factor concerns the application of the Last Planner System. This system relies very heavily on interaction and close communication between sub-contractors, facilitated mainly by the main contractor (AlSehaimi, Tzzortopoulos and Koskela 2009; Brady, Tzzortopoulos and Rooke 2011).

No other lean construction techniques are discussed. This may provide some explanation of the conflicting results as the respondents that took part in this research project used a wide range of lean techniques and not just Last Planner. In addition, the sample size was <5 in the failures group and this may have had an affect. However, it has been established that sample sizes $n<5$ can effectively be used for two sample T tests and that the Mann Whitney is more conservative (Winter 2013).

The key word may possibly be "between" rather than "communication". It is possible that the main contractor could achieve excellent communication with each individual supplier and that project success is not reliant on communication *between* suppliers.

However there is no satisfactory explanation for the conflicting results. It is considered that this factor would indeed be critical in an application of the Last Planner System but is probably not universally important for lean construction to succeed. Therefore it is concluded that this factor is important but does not rank as critical.

5.6.2 CSF 20 - There must be a high level of collaboration with sub-contractors

This study once again returned conflicting results: On the one hand, the level of collaboration was significantly higher for successful projects than evidenced for the failures; on the other hand, this study returned a verdict that the level of collaboration did not significantly affect the outcome either way. One possible interpretation is that whilst the level of collaboration is important, it may not be a decisive factor in terms of success or failure. Similar to CSF 15 (supplier communication), this factor is likely to be far more important in applications of the Last Planner System which would rely heavily on supplier collaboration for success. As in CSF 15, it is concluded that this factor is important but may not be universally critical.

5.7 SUMMARY

This discussion provides further insight to the relevance of the success factors examined within the context of the literature specific to the construction sector and also common sense. One failure of the methodology was exposed and the result for factor four is unknown.

Following the discussion surrounding cause and effect links between factors it is suggested that capability of management, a long term client or work-stream and the right facilitator are the three factors that possess the greatest ability to positively affect the outcome of a lean intervention or transformation. The summary of results has been updated in Table 5.7 below to reflect the points discussed.

Table 5.7 Updated summary of results

CSF	No.	Test	Mode	Median	U Value	P Value	% that said >4	Mean	Conf. Level	Null Rejected Y/N	Criticality Status		
											Y	I	N
A crisis is necessary	1	Fishers				0.298			70.2%	N			N
There must be buy in from team	2	Mann Whitney 1 tail			118	0.013			98.7%	Y	Y		
There must be buy in from senior management	3	Mann Whitney 1 tail			116	0.07			93.0%	Y	Y		
Improvement efforts must be process, not result focused to succeed	4	Fishers				1			0%	N	Unknown		
Improvement goals must be set	5	Fishers				0.596			40.4%	N			N
The focus must be on the end user to succeed	6	Fishers				1			0%	N			N
The intervention must involve all stakeholders	7	Fishers				0.383			61.7%	N			N
Management must be capable	8	Fishers				0.034			96.6%	Y	Y		
Senior management must be directly involved	9	Fishers				0.067			93.3%	Y	Y		
Management must stay focused on the efforts	10	Mode, Median, Wilcoxon	5	5		5.87×10^{-7}	100%	97%	99.9%	Y	Y		
Appropriate training is critical for success in lean interventions	11	Mode, Median, Mean,Wilcoxon	4	4		1.31×10^{-5}	94%	85%	99.9%	Y	Y		
There must be a learning by doing approach	12	Fishers				0.355			64.5%	N			N
Actions must be closed by the team	13	Mann Whitney 1 tail			94.5	0.078			92.2%	Y	Y		
People must be allowed enough time to spend on improvements	14	Mean, Z test				0.003		74%	99.7%	N	Y		
A high level of communication between suppliers is key	15	Mann Whitney 1 tail			38	0.172			82.8%	N		I	
The effect of the level of communication	15a	Mann Whitney 2 tail			48.5	0.029			97.1%	Y		I	
The extent Silo thinking was present	16	Mode, Median, Mann Whitney 1 tail	4	4	44	0.866			13.4%	N			N
The effect silo thinking had on success	16a	Mann Whitney 1 tail	3	3	45	0.883			11.7%	N			N
Relevant data were available	17	Fishers				0.006			99.4%	Y	Y		
Need more than 1 lean tool	18	Mode, Median, Wilcoxon	4	4		8.2×10^{-6}	97%	87%	99.9%	Y	Y		
A long term client relationship or work stream is critical for success	19	Fishers				0.038			96.2%	Y			
The effect of a long term client - good or bad	19a	Mann Whitney 2 tail			110.5	0.004			99.6%	Y	Y		
There must be a high level of collaboration with sub-contractors	20	Mann Whitney 1 tail			45.5	0.033			96.7%	Y		I	
Effect of the level collaboration between suppliers	20a	Mann Whitney 2 tail			39.5	0.225			77.5%	N			
The right facilitator is critical	21	Mode, Median, Mean,Wilcoxon	5	5		0	100%	95%	100%	Y	Y		
Age is an issue	22	Mean, Z test	0	0		0.991		30%	1%	N			N
Must be a no blame culture	23	Mann Whitney 1 tail			28	0.024			98%	Y	Y		

CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

6.1 Fulfilment of the aims and objectives of this research

The research question and main aim concerned the identification of critical success factors necessary for successful lean construction interventions, leading to the provision of guidance that might inform future efforts to deploy lean construction. This chapter sets out a summary of Twenty-Eight conclusions drawn from the research and shows from which section of this thesis they emanate and how these relate to the fulfilment of the aims and objectives stated in Chapter One.

Research Objective 1. *Explore the emergence of lean production as a concept and contributions of its key historic influencers.*

6.2 Literature review

6.2.1 Emergence of Lean as a concept

1) The term "lean" appeared to emerge after the publication of the "Machine that Changed the World" in 1990, and was mainly concerned with the Japanese automotive sector. However, the origins of lean thinking can be found a century earlier and were applied in a much wider context than just the car industry. Of particular interest for the construction sector is Frank Gilbreth who had a background as a contractor and worked successfully to improve the productivity of bricklayers. It is regrettable that Gilbreth is not more widely known as an innovator and lean thinker who emerged from the construction sector; if this were so then perhaps the construction sector would not be so quick to label lean as a "manufacturing thing".

2) Whilst Toyota provided the exemplary model of lean thinking the concept is difficult to define and no satisfactory definition of lean currently exists.

Research Objective 2. *Work towards an operational definition of lean production by exploring the features that differentiate lean from other improvement methods.*

3) To help define lean, there is a need for "operational definitions" and for a clear statement on what makes it different from other improvement methodologies. Three key characteristics that differentiate lean were identified that may help to define it: low levels of Work in Progress, the concept of the Visual Workplace and Problem Solving.

Research Objective 3. *Examine differences between production and construction and work towards an operational definition of lean construction.*

6.2.2 Towards a definition of Lean Construction

4) The lack of a suitable definition of Lean Construction was identified.

5) There are many similarities between construction and shipbuilding, with resources flowing over the product and products made "one off" to order.

6) Key peculiarities of construction include fixed position manufacturing, rooted in place, (site-production), one-of-a-kind production, client involvement in production and temporary organization. The peculiarities should not automatically be taken to be problems or wasteful, however most efforts to apply lean construction focus on mitigating or reducing them.

7) Previous literature on the subject does not fully discuss sectorial motivation to improve and the rooted in place peculiarity is identified as a key motivational barrier. This is because the lack of transportability of buildings does not allow true global competition as in some other industry sectors, most notably the automotive sector: even though foreign

construction companies operate successfully in the UK, the sub/contract labour base which is also the source of the largest cost variable is predominantly domestic.

8) There appears no practical reason why the three key characteristics of TPS can not work in the construction sector despite the peculiarities identified.

9) The same three key characteristics of low levels of Work in Progress, the Visual Workplace and Problem Solving identified from TPS, combined with hard metrics of performance could also serve as a good starting point to develop an operational definition of lean construction.

10) In addition, after considering the differences between sectors – particularly rooted-in-place; and efforts to apply lean thinking in construction it was concluded that the real difference between the uptake of Lean Production and Lean Construction is not in the techniques, philosophy or characteristics but in the industry's ability or willingness to adopt the new philosophy.

***Research Objective* 4**. *Elicit from the literature those factors that are considered critical for success.*

6.2.3 Critical success factors for lean construction

11) Nineteen critical success factors were identified, seven of these from construction related literature and twelve from other sectors as shown in Table 2.7 on page 52.

12) It could not be established how or if these factors had been tested in the construction industry and a gap in knowledge was perceived in terms of which factors are most important for successful lean construction interventions.

6.3 Methodology

***Research Objectives* 5 and 6**. *Test the relevance of those factors identified in the literature by conducting interviews with construction professionals in a pilot study and capture any new factors that emerge.*

6.3.1 Pilot Study

13) The pilot study produced the following outputs:

- Nineteen factors from the literature were tested for presence and relevance, of which sixteen were carried forward into the main study and three were dropped. This is summarised in Table 2.7 on page 52: factors one to sixteen were carried forward and seventeen to nineteen dropped.

- Seven new potential factors emerged and were carried forward into the main study.

6.3.2 Main Study

***Research Objective* 7**. *Design a suitable research methodology to test the relative importance of each of the factors.*

14) After reviewing the effectiveness of the approach taken in the pilot study 23 hypotheses were formed together with a revised interview structure.

15) It was concluded that face-to-face interviews were the most appropriate data gathering method despite the additional cost.

16) The statistical methods chosen would work with sample sizes of ≥ 5.

17) Eighteen factors were linked to failure or success and five were not. Types of data generated were categorical, binary and narrative. This resulted in the need for four different types of hypothesis test in addition to content analysis and descriptive statistics of mode, median and mean as shown in Table 6.1 below.

Table 6.1 Characteristics of data generated by the responses and analytical methods used

CSF	Linked to an identifiable intervention success or failure Y/N?	Contingency pairs or single group data.	Categorical data	Binary data	Narrative	Analytical Methods Used
1	Y	Pairs		Y		Fishers Exact Test
2	Y	Pairs	Y			Mann - Whitney U Test
3	Y	Pairs	Y			Mann - Whitney U Test
4	Y	Pairs		Y		Fishers Exact Test
5	Y	Pairs		Y	Y	Fishers Exact Test and content analysis
6	Y	Pairs		Y		Fishers Exact Test
7	Y	Pairs		Y	Y	Fishers Exact Test and content analysis
8	Y	Pairs		Y	Y	Fishers Exact Test and content analysis
9	Y	Pairs		Y	Y	Fishers Exact Test and content analysis
10	N	Single	Y			Wilcoxon One sample Signed Rank Test and mode,median,mean
11	N	Single	Y			Wilcoxon One sample Signed Rank Test and mode,median,mean
12	Y	Pairs		Y		Fishers Exact Test
13	Y	Pairs	Y		Y	Mann - Whitney U Test
14	N	Single		Y		Mean and Z Test
15	Y	Pairs	Y			Mann - Whitney U Test
16	Y	Pairs	Y		Y	Mann - Whitney U Test
17	Y	Pairs		Y	Y	Fishers Exact Test
18	N	Single	Y			Wilcoxon One sample Signed Rank Test and mode,median,mean
19	Y	Pairs	Y	Y		Fishers Exact Test
20	Y	Pairs	Y			Mann - Whitney U Test
21	N	Single	Y		Y	Wilcoxon One sample Signed Rank Test and mode,median,mean
22	N	Single		Y	Y	Mean and Z Test
23	Y	Pairs	Y		Y	Mann - Whitney U Test

18) It is concluded that whilst the methodology as a whole worked reasonably well it was unnecessarily complex, requiring significant time for transcription and analysis.

19) The use of narrative to aid clarity and improve the richness of data for certain questions worked well, allowing the respondents freedom to choose their own words rather than be “forced into a box”.

6.4 Results

18) Statistical tests on data associated with the 23 factors found that thirteen were critical and eight not critical at the 90 per cent confidence level as shown in Table 6.2 below. Two factors returned conflicting results and these are shown separately in Table 6.3.

19) In addition 25 of 31 respondents declared their intervention to be a success and it was not known prior to interview whether this would be the case. The probability of this happening by chance is < 1 per cent. In other words, lean thinking works in a construction context.

20) Descriptors of success were recorded and 70 per cent of the responses were noted as time saved, cost saved, a measurable result and people engagement.

21) Of the sixteen factors identified as critical in the literature and carried forward to the main study, seven returned results of not critical and one returned conflicting results that were discussed.

22) Of the seven factors derived from the pilot study, five were found critical, one not critical and one returned conflicting results.

Table 6.2 Summary of hypothesis test results

No.	CSF	Source	*p* Value	Confidence Level	Critical Y/N
21	The right facilitator is critical	Pilot	0	100%	Y
10	Management must stay focused	Literature	5.87×10^{-7}	99.9%	Y
18	More than 1 lean tool	Pilot	8.2×10^{-6}	99.9%	Y
11	Appropriate training	Literature	1.31×10^{-5}	99.9%	Y
14	People must be allowed to spend enough time to spend on improvements	Literature	0.003	99.7%	Y
19	Long term client / work-stream	Pilot	0.004	99.6%	Y
8	Management must be capable	Literature	0.034	99.6%	Y
17	Relevant data available	Pilot	0.006	99.4%	Y
2	Buy-in from the team	Literature	0.013	98.7%	Y
23	Must be a no-blame culture	Pilot	0.024	97.6%	Y
9	Senior management directly involved	Literature	0.067	93.3%	Y
3	Must be buy-in from senior management	Literature	0.07	93%	Y
13	Actions must be closed	Literature	0.078	92.2%	Y
1	A crisis is necessary	Literature	0.298	70.2%	N
12	A learning by doing approach	Literature	0.355	64.5%	N
7	Must involve all stakeholders	Literature	0.383	61.7%	N
5	Improvement goals must be set	Literature	0.596	40.4%	N
16	The effect of silo thinking	Literature	0.883	11.9%	N
22	Age is an issue	Pilot	0.991	0.9%	N
4	Efforts must be process focussed	Literature	1	0%	N
6	Must focus on the end user	Literature	1	0%	N

Table 6.3 Hypothesis tests returning conflicting results

<table>
<tr><th>No.</th><th>CSF</th><th>Source</th><th>p Value</th><th>Confidence Level</th><th>Critical Y/N</th></tr>
<tr><td>15</td><td>Must be a high level of communication between suppliers</td><td rowspan="2">Literature</td><td>0.172</td><td>82.8%</td><td rowspan="2">Important</td></tr>
<tr><td>15</td><td>The effect of communication between Suppliers</td><td>0.015</td><td>98.5%</td></tr>
<tr><td>20</td><td>Must be a high level of sub-contractor collaboration</td><td rowspan="2">Pilot</td><td>0.033</td><td>96.7%</td><td rowspan="2">Important</td></tr>
<tr><td>20</td><td>The effect of collaboration between subcontractors</td><td>0.225</td><td>77.5%</td></tr>
</table>

***Research Objective* 8**. *Derive from the results the implications for industry.*

23) Some of the popular lean literature may be providing erroneous advice when applied in the context of the construction sector. This research has shown that the following factors whose presence is deemed necessary for success by the literature are not in fact critical for success:

- There must be a crisis.
- Improvement goals must be set.
- The focus must be on the end user to succeed.
- The intervention must involve all stakeholders.
- There must be a learning by doing approach.
- A high level of communication between suppliers is critical.
- Must overcome silo thinking to succeed.

6.5 Discussion

24) It became apparent that interdependencies were likely and an assessment of the statistically significant factors was that “buy-in” appeared a dominant pre-occupation with the respondents, both from the improvement team and from management. It was also conceived that “buy-in” could be construed as a result or effect as well as a cause of success.

25) Three factors appeared to possess a higher ability to influence most of the others. These were: a long-term client or work stream, capability of management and the right facilitator. This is illustrated in Table 5.3 on page 132 where the lowest counts of “causes”, highlighted in yellow, are observed to provide the highest counts of “effects”, highlighted in orange.

26) Building on this logic, the factors are listed in the potential order of importance in Table 5.5 on page 135, which shows each factor ranked by its “influence factor” derived by dividing the number of effects by the number of causes.

27) A methodological error caused one factor – “must be process not result focussed” to be re-classified from “not significant” to “not proven either way”.

28) Two outputs provided conflicting results because each contained a two-part question and though the results from one part were found to be statistically significant, this was not the case in the second part. These were:

- *A high level of communication between suppliers is critical for success*

  and

- *A high level of sub-contract collaboration is critical for success*

After comparing the results to the literature and re-examining the methodology, it was concluded that these factors were not universally critical but important under certain circumstances.

6.6 Limitations of this work

Despite the best efforts of the questioning methodology to elicit accurate and true responses, it is still possible that certain factors could have led to respondent error. Recall bias can lead to a respondent misrecalling the facts and social desirability bias might lead a respondent to respond in a fashion that is thought correct, rather than true. In addition, failure or success of the intervention in focus may have stirred emotion sufficient to bias responses to the other questions. Two of the factors tested in this thesis concerned working with suppliers and the concepts of communication and collaboration returned conflicting results which, after re-examination and logical discussion were eventually categorised as "important". It may be the case that the reason for the uncertain results was because not all the interventions tested concerned the engagement of sub-contractors. In fact the data sets for these factors comprised eighteen successes and four failures. There are differences of opinion (mentioned earlier in Section 3.8.1) but some hold that the statistical tests used must have a sample size ≥5 and this was not the case with these factors. The failure group was *n*4. In addition, an error of methodology was found during the examination of the factor concerning process rather than result focussed efforts and the result had to be discarded. The sample of respondents came from a mix of private and public sector staff involved in construction activities that included new build, refurbishment, and planned and re-active maintenance. It may well be the case that different results might have been obtained if the research had focused solely on just one of these sub-sectors. For example, the drivers for public sector maintenance might be different to private sector new build construction.

The assessment of interdependencies appeared late in the research when reviewing the results and with hindsight the methodology could have been adjusted to allow multi-factorial hypothesis tests but this would have been difficult if not impossible with the available data. The discussion however follows a logical path leading to useful further insights.

It is of course possible that other critical factors exist but were missed by this research, especially when considering the wider issue of a lack of uptake by the sector in general. It may well be the case that systemic conditions such as taxation policy, skills availability and regulation, project finance models and procurement methods need to be reviewed and amended to provide a suitable economic environment for lean construction to flourish.

6.7 Conclusion

The biggest identifiable cost variable in the construction sector is labour productivity (Horner and Duff 2001). To date, failure to properly address this is compounded with a widespread skills shortage forecast in the UK (Chevin 2014). The successful deployment of lean thinking within the construction sector is an industrial imperative and this research helps to clarify some of the myths that have emerged over time and provide guidance of what is truly important to assist future efforts.

It appears that getting “buy-in” is the key to success for lean construction, at all levels of management. The greatest influences on buy-in appear to be clients, capability of management and the right facilitator.

6.8 Original contribution to knowledge

This thesis provides original contribution to knowledge in the following ways:

Firstly, by working towards an operational definition of lean and lean construction that could not be found in the literature. Specifically, the question of what is actually different about lean thinking compared to other improvement methodologies has been examined and identified. Whilst a final definition was not formed, good progress was made and the work will inform future research in this subject.

Secondly, sixteen factors were identified as critical in the literature and carried forward to the main study, but seven of these returned results of not critical when subjected to statistical tests of the gathered data, one of which was discounted and classified as unknown due to an error of methodology. In addition, seven new factors were derived from the pilot study and of these five were found to be critical. Thus this work has identified thirteen factors which appear to be critical to success in implementing lean interventions in the construction industry.

Lastly, interdependencies between the statistically significant critical success factors were evaluated and whilst the subjective nature of the analysis might be improved three factors were identified that possess the ability to exert more influence than the others. These were (1) A long term client or work-stream, (2) capability of management and (3) the right facilitator.

***Research Objective* 9**. *Produce summary guidance based on research.*

6.9 Guidance For Lean Construction Practitioners based on this research

Undertaking a Lean Construction intervention can by no means take a one-size fits all approach. However, this research has clarified certain factors that if paid due attention will undoubtedly help to ensure success.

6.9.1 Guidance based on work towards an operational definition of lean construction

Firstly, it is suggested that if a lean approach is desired then there must exist a common understanding of what this means. The guidance offered is therefore based on the work toward a definition of lean production and lean construction. This was in four parts.

1. *Minimise WIP*. This is similar to a focus on improving flow but is perhaps easier to understand and implement. This is because it is relatively easy to measure WIP and the resultant improvements from its reduction. However, when using this as a strategy for planning tasks in projects, the level of supplier collaboration and communication necessary for success will raise proportionately as the level of WIP reduces.
2. *Utilise the concepts of the Visual Workplace*. In construction this means making invisible processes visible. People will naturally “do the right thing” if it is easy to physically see what to do. Consider that one of the last items to be fixed in place in a construction project is signage. How does a new worker to the site easily find their way around then? In a design environment much of the information is only visible to individuals but not the whole team. Many problems are caused by a lack of visibility and avoided by increasing it.

3. *Problem Solving*. Engage in continuous improvement by actively seeking out problems to work on, collaboratively with employees and suppliers.
4. Establish a method of measuring progress using unambiguous *hard metrics of performance*. This is not the same as goal or target setting but can create the ability to see the impact of any improvements taken.

6.9.2 Guidance based on the Critical Success Factors

Thirteen factors were identified as critical for success in this research. Further to the discussion chapter it is clear that these factors are inter-related and also that the creation of crisis cannot be relied upon to work reliably in a construction setting. This then means that a focus on getting buy-in is essential. Referring to Table 5.3 on page 132 it can also be observed that three of the factors appear to possess the ability to exert more influence than the others. This does not mean that the rest are less important but following the order shown by table 5.5 on page 135 comments on each are provided below.

- The right facilitator – This might be an internal or external facilitator but the key capabilities to look for as identified in this research that define "right" are: -
    - Specific construction knowledge and empathy with the improvement team
    - The ability to make the concepts relevant
    - Ability to keep the team on track
    - Infectious enthusiasm
    - Brings discipline
- Management must be capable – capability of management in the context of this research was specifically identified as the ability to get buy-in and foster teamwork.

- A long-term client or work-stream – the guidance is that this is a key enabler of lean and is a good place to start as well as a worthy aspiration.
- Appropriate training – Lean thinking doesn't achieve anything without lean doing. There now exists an international standard in ISO 18404 that outlines what a lean practitioner should know and be able to practically apply, however this has yet to be contextualised for construction.
- Senior management must be directly involved – if its important it should be led directly at the most senior level. Lean construction won't work as the "next initiative" and cannot be successfully delegated: constancy of purpose is required. Lean improvement is not achieved by sitting around a table in the board-room.
- Management must stay focused – If management do not see things through it is likely no-one else will. Formal periodic reviews are recommended to ensure focus is maintained.
- People must be allowed to spend enough time – the research indicates that 20% of a persons' time is appropriate. It is also considered that an alternate approach is that if a new process or method is introduced, then an existing method or process must be replaced and ideally rationalised. For example, site-managers will typically see a new weekly planning schedule as "another piece of paper" to fill in. For success to be sustained this needs to replace or rationalise an existing practice. If one new form is introduced, one or more must go.
- Buy-in from senior management – without this the effort will likely fail. The Asda case study presented by Beer (Beer 2003) makes interesting reading but is not for the faint hearted CEO. Different ways to get buy-in no doubt exist, but full involvement at the start is key to avoid "not invented here" syndrome.
- Must be a no-blame culture. The successful introduction of new processes requires risk taking and if failure is penalised no-one will want to take risks.

- Must use more than one tool – This is because the focus must not be on tools, but on a higher philosophy. If this is the case, then it is likely the team will use whatever tools are appropriate.
- Actions must be closed by the team – This is closely linked to the involvement of senior management and the team should be required to regularly report progress in terms of what actions have been agreed and their status.
- Relevant data must be available or created – This could form part of the appropriate training. Teams or practitioners should know how to collect, analyse and communicate improvement data. "Relevant" in this context means a hierarchal approach to data analyses that allows progress toward root cause problem solving. High level KPI's do not provide any useful information in terms of how to improve.
- There must be buy in from the team – As observed in Chapter 5, buy-in could be taken to be an outcome as well as an enabler, and this research did not directly explore how the successful teams achieved buy-in. However, it is likely that management of the other factors will influence the level of buy-in achieved.

6.10 Recommendations for future research

Given that clients appear to have a particularly high influence on the uptake of lean construction, it might speed up adoption by industry if they began to demand it. It is known to the researcher at the time of writing that this is happening in Ireland where client demands have acted as a catalyst for the rapid uptake of lean construction (Sexton 2014).

A simple way to articulate what lean construction really means and the benefits it can bring to all stakeholders would be most helpful. In other words, a proper operational definition of lean construction is required. If such a definition existed, a correlation could potentially be established between the extent to which lean construction was used and project success. If this held true it is likely that clients would begin to demand it, thus providing both extrinsic and intrinsic motivation or buy-in.

It is suggested that further work on a practical definition of Lean Construction could be beneficial to both research and industry.

In addition, it has been shown that crisis does not have the same effect in construction as in other sectors in terms of providing motivation to improve or adopt lean thinking. In this light a full examination of what conditions will cause the construction sector to adopt lean thinking or “buy-in” would be most helpful. This should include a comparison of different systemic sectoral conditions such as taxation, skills availability and procurement methods that might exist in different nations and their subsequent effects on performance.

APPENDIX ONE

Steve Ward PhD research Interview Questions for Main Study

Background text/intro to interview.

This research seeks to identify an improved approach to deploying lean thinking by examining a sample of efforts to date. I am interested in failures as well as success stories. A literature review as well as a pilot study has been conducted to identify factors that may be critical to successful lean intervention. The following questions have been designed to provide clarification of the identified factors.

Please think of a lean intervention you have been personally involved in, either successful or unsuccessful.

1. Was the effort successful?

   Total Failure---Partial Failure---Mixed Results----Successful----Exceeded Expectations
   c. How do you know that? E.g. measured results?
2. What prompted you to start the intervention? (It wont work without a crisis)
   Did you choose to do it or was made to do it?
3. What was the level of buy-in from (Must have buy-in from a, and b) *time based*
   a. Senior management? i.e. director level
      None, a little, some, quite a lot, substantial.
   b. The improvement team?
      None , a little, some, quite a lot, substantial.
      c. Did it change over time?
4. When deciding the focus or project scope, which of the two following statements more closely fits what you did. (Must be process focussed rather than results focused)
   a. " the aim is to simplify, reduce the number of steps required and remove waste, and generally improve the process ,which we have faith will lead to a better result
   b. the aim is to improve performance from a to b with 'a" being the lead time or cost or other tangible measurable result
5. Were improvement goals (deliverables) for the project set, (Improvement goals were set)
   a. and if so by whom?
6. Thinking about the improvement project focus, who was the main stakeholder you were trying to please? E.g the client, the public (end user) , or the boss? (must be focus on customer/end user?)
7. Which stakeholders were involved in the improvement process? (Must Involve all stakeholders)
   a. If any were missing what effect did this have?
8. What sort of data do you think would be beneficial for improvement activity? (Relevant Improvement Data were available) *or were created*
   a. Did you have any of this available for your project and
   b. Did this help or hinder your efforts?

9. What particular management skills or attributes do you think are essential for a lean intervention? (Capability of Management is critical)
    a. Were these skills present in your improvement team?
10. Were senior management personally involved? (Senior Management must be personally involved) Senior means director level or Contracts Man. In large org.
    a. If so what sort of things did they actually do?
11. How important is it that management should "stay focused" on the improvement efforts? (Management must stay focused on improvement for success) Unimportant, of little Importance, don't know, Important, Vital
12. In the context your Lean intervention/s, how important is specific training in the lean philosophy and techniques? (Appropriate training must take place for success)
    Unimportant, of little Importance, don't know, Important, Vital
13. Do you have experience of more than one lean facilitator/trainer. (The right facilitator is key)
    a. If yes how important is the facilitator in ensuring success?
        Unimportant, of little Importance, don't know, Important, Vital
    b. If a contrast exists between trainers what did the most successful one do that the other(s) didn't?
14. This question is about classroom training v teaching v doing. (It must be a learning by doing approach)
    a. What sort of approach did the facilitator take?
15. To what extent were the actions closed?
    None closed, less than 25% got closed, between 25% and 50% , 50 to 75, 75 to 100
    a. Did someone take personal responsibility for ensuring the team closed the actions?
    b. Who was this? What's their position in the company?
16. How much of their time must people spend on an improvement activity for a successful outcome? (People must be allowed to spend time on improvements)
    5 -20%, 20-40%, 40-60%, 60-80%, 80-100%.
    a. Can success be achieved without taking time away from work?

17. How many different improvement tools were used? (More than 1 tool must be used for success)
    a. How important is it that more than 1 tool is used?
        Unimportant, of little Importance, don't know, Important, Vital
18. This is about the influence the type of contract/client relationship may have on the success of an intervention? i.e. was it a long term client relationship? (Must be a long term client for success)
    a. What effect did this have? *Good or bad- (level of influence)*
        None, a little, some, quite a lot, substantial

19. This question is about supply chain and is relevant if your efforts were project focused and needed sub/c. (High Collaboration between suppliers is key)
    a. What was the level of collaboration like between suppliers
       Adversarial, tolerated each other, neither adversarial or collaborative, collaborative, highly collaborative
    b. What effect did this have? Scale
       Very negative, negative, no effect, positive, very positive
20. This concerns working with sub contractors to deliver projects.

a. How would you describe the level of communication between the sub-contractors? (High level of communication between suppliers) scale

Non-existent, Low, moderate, High, Very high

b. How did this affect the outcome?
   No influence, small influence, some influence, positive influence, extremely positive influence

21. To what extent was silo thinking present in your project? (Must overcome silo thinking to succeed)Not at all, a little, some, quite a lot, all-pervasive. *Time Based*
    a. To what extent did this affect your efforts?
       Had no affect, minimal effect, had some effect, made it very difficult and eventually stopped, Stopped Them
    b. What did you do about this?
    c. What happened as a result?

22. To what extent did a blame culture exist in your organisation during the efforts? (There must be a no-blame culture to succeed) None, a little, some, quite a lot, substantial.
    a. Was anything done to address this?
23. Do you think the age of the improvement team members is a critical factor for success? (It wont work if the improvement team are too old)
    a. How old is too old?
    b. How young is too young?
    c. Why is this?

APPENDIX TWO

List of Interviews

Pilot Study

No.	Name	Job title at time of Interview	Company at time of interview	Date
1	Marcus Dicks	Best Practice & Quality Manager	ISG Pearce	06/07/10
2	Andrew Taylor	Business Development Director	ISG Pearce	05/08/10
3	Andrew Staniforth	Director of Customer Experience	ISG Pearce	05/08/10
4	Darrin Davies	Head of Property Services	Family Housinhg Association	23/07/10
5	Ceri Thomas	Senior Building Surveyor	Family Housinhg Association	23/07/10
6	Paul Philiips	National Frameworks Director	Morgan Sindall	21/06/10

Main Study

No.	Name	Job title at time of Interview	Company at time of interview	Date
1	Bruce Patrick	Repaird & Maintenance Manager	Dundee City Council	15/03/12
2	Tony Dolan	Performance Manager	Dundee City Council	15/03/12
3	Kenny Doig	Assistant Maintenance Manager	Dundee City Council	15/03/12
4	Duncan McDonald	Housing Repairs Centre Team Leader	Dundee City Council	15/03/12
5	James Player	Operations Director	Cowlin Construction Ltd	23/03/12
6	Lynne Panes	Key Account Manager	S Dudley & Sons	23/03/12
7	Steven Allan	Senior Estimator	Tayside Contracts	15/03/12
8	Dougie Mckay	Road Maintenance Partnership Manager	Tayside Contracts	15/03/12
9	Ian Stott	Site Agent	Tayside Contracts	15/03/12
10	Layra Dysart	Business Improvement Manager	Tayside Contracts	12/08/11
11	Scott Banks	Project Manager	Tayside Contracts	15/03/12
12	Angus MacKinnon		Tayside Contracts	15/03/12
13	Nicola John	General Manager	Service Total	16/07/12
14	Peter Morse	Managing Director	Service Total	14/08/12
15	Nigel Hawkins	Senior Surveyor	Family Housing Association	16/07/12
16	Stuart Thomas	Performance Improvement Manager	Family Housing Association	16/07/12
17	Bill Haines	Operations Director	Stepnell Ltd	18/07/12
18	Mark Wakeford	Managing Director	Stepnell Ltd	18/07/12
19	Ian White	Senior Planner	ISG Pearce Ltd	20/07/12
20	Andy Bodily	Site Manager	Deeley Construction Ltd	26/07/12
21	Jayne Rowland Evans	Director	GKR Ltd	06/08/12
22	Ceri Dawe	Supervisor	Gibson Heating Ltd	07/08/12
23	Jenny Hudson	Director	G.M.Jones	09/08/12
24	Martin Gunn	Project Manager	Anwyl Construction	09/08/12
25	Alex Read	Business Improvement Manager	Read Construction	09/08/12
26	David Cloete	Project Manager	Read Construction	09/08/12
27	Anthony Thomas	Managing Director	A S Wellington Ltd	14/08/12
28	Rob Norman	Managing Director	Jistcourt Ltd	14/08/12
29	Sean Bradley	Commercial Director	Farrans Construction Ltd	22/08/12
30	Colwyn Knight	Director	Castleoak Ltd	03/09/12
31	Nyron Wood	Site Manager	Jehu Construction	03/09/12

REFERENCES

ABDELHAMID, T.S. (2007). *Lean Construction Principles* - Graduate class offering at Michigan State University. Michigan, USA.

ALSEHAIMI, A., TZZORTZOPOULOS, P. AND KOSKELA, L. (2009). '*Last Planner System: Experiences From Pilot Implementation in the Middle East'*, in: Cuperus, Y. and Hirota, E.H., 17th Annual Conference of the International Group for Lean Construction. Taipei, Taiwan, 15-17 July 2009: 53-66.

ANDERSON, J., JONG-MIN, K. AND ENGIN, S. (2004). *Choosing the Right Nonparametric Method for the Right Data Set* [online] Available from http://mnstats.morris.umn.edu/introstat/nonparametric/learningtools.html. Last accessed 6th April 2015.

BALLARD, G. (2000a). *The Last Planner System of Production Control* - PhD Thesis. Faculty of Engineering, University of Birmingham

BALLARD, G. (2000b). *Lean Project Delivery System* - Lean Construction Institute (LCI white paper-8 – September 23, 2000 (Revision 1)

BALLARD, G. AND HOWELL, G. (1994). '*Implementing Lean Construction: Improving Performance Behind the Shield'*. 2nd Annual Meeting of the International Group for Lean Construction. Santiago, Chile. Available in Lean Construction, A.A. Balkema Publishers. Rotterdam, Netherlands, 1997.

BALLARD, G., AND HOWELL, G. (1997). *'Implementing lean construction: Improving downstream performance.'* Lean construction, Balkema, Rotterdam, Netherlands, 111–125.

BALLARD, G. & HOWELL, G. (1998). *'What Kind of Production Is Construction?'* In:, 6th Annual Conference of the International Group for Lean Construction. Guarujá, Brazil, 13-15 Aug 1998.

BATALI, J. (2007). *z-Test Approximation of the Binomial Test* [online] Available from http://www.cogsci.ucsd.edu/classes/SP07/COGS14/NOTES/binomial_ztest.pdf. Last accessed 27th April 2015.

BATEMAN, N. (2001). *Sustainability: A Guide to Process Improvement*. SMMT Industry Forum, Lean Enterprise Research Centre. Cardiff Business School, Cardiff.

BEER, M. (2003). '*Why Total Quality Management Programs Do Not Persist: The Role of Management Quality and Implications for Leading a TQM Transformation'*. Decision Sciences, Vol 34: 623–642.

BEER, M., EISENSTAT, R.A. AND SPECTOR, B. (1990). *Why change programmes don't produce change*: Harvard Business Review November-December 1990

BERNARD WILLIAMS ASSOCIATES (BWA). (2006). *Benchmarking of use of Construction (Costs) Resources in the Member States* (Pilot Study) [online] Available from http://ec.europa.eu/DocsRoom/documents/5141/ attachments/1/ translations/en/ renditions/native. Last accessed 18th June 2015.

BICHENO, J. (2000). *The Lean Toolbox*. PICSIE Books, Buckingham.

BOSLAUGH, S. (2012). *Statistics in a Nutshell*: A Desktop Quick Reference – 2nd Edition. O'Reilly Media, USA

BRADY, D., TZZORTOPOULOS, P. AND ROOKE, J. (2011). '*An Examination of the Barriers to Last Planner Implementation'*, in: Rooke, J. and Dave, B., 19th Annual Conference of the International Group for Lean Construction. Lima, Peru, 13-15 July 2011.

BRYANT, A. AND CHARMAZ, K. (2010). *The Sage Handbook of Grounded Theory* (Sage Handbooks). Sage Publications Ltd.

BRYMAN, A. (2004). *Social Research Methods* – 2nd Edition. Oxford University Press, Oxford

BUCHANAN, D., FITZGERALD, L., KETLEY, D., GOLLOP, R., JONES, J. L., LAMONT, S. S., NEATH, A. AND WHITBY, E. (2005). *No going back: A review of the literature on sustaining organizational change*. International Journal of Management Reviews, Vol 7: 189–205.

CAMPBELL, M.J. (2006). *Parametric and Non-parametric tests for comparing two or more groups* [online] Available from http://www.healthknowledge.org.uk/public-health-textbook/research-methods/1b-statistical-methods/parametric-nonparametric-tests. Last accessed 6th April 2015.

CHEVIN, D (February 2014) *No more lost generations creating construction jobs for young people*. London: House of Commons.

COLLINS, J.C. (2001). *Good to Great: Why Some Companies Make The Leap…And Others Don't*. HarperBusiness. New York, NY.

COLMAN, A.M., NORRIS, C.E. AND PRESTON, C.C. (1997). *Comparing rating scales of different lengths: Equivalence of Scores from 5-Point and 7-Point Scales*. Psychological Reports, Vol 80(2): 355-362.

COX, J.F. AND SCHLEIER, JR, J,G. (2010). *Theory of Constraints Handbook - 1st Edition*. McGraw-Hill Education, New York.

DAUBER, V. F. (2003). *Measuring and minimising waste in construction by applying lean thinking*. PhD Thesis. University of Dundee, Dundee.

DE WINTER, J.C.F. (2013). *Using the Student's t-test with extremely small sample sizes.* Practical Assessment, Research and Evaluation, 18 (10), pp. 1-12. [online] Available from http://pareonline.net/pdf/v18n10.pdf. Last accessed 26th April 2015.

DEMING, W. (1986). *Out of The Crisis*. Massachusetts Institute of Technology, Centre for Advanced Engineering Study. Cambridge, MA.

DEMING, W. (1994). *The New Economics*. Massachusetts Institute of Technology, Centre for Advanced Engineering Study. Cambridge, MA.

DEPARTMENT FOR BUSINESS, ENTERPRISE AND REGULATORY REFORM (BERR). (2007). *Construction Statistics Annual - August 2007* [online] Available from http://aalookup.bis.gov.uk/construction/Constats2007.pdf. Last Accessed 12 June 2015.

DEPARTMENT FOR BUSINESS, INNOVATION AND SKILLS (BIS). (2013) *Industrial Strategy: government and industry in partnership: Construction 2025* [online] Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis-13-955-construction-2025-industrial-strategy.pdf. Last accessed 16th June 2015.

DEPARTMENT FOR TRADE AND INDUSTRY (DTI). (2006). *Report on The Industry Forum Adaptor Programme* [online] Available from http://webarchive.nationalarchives.gov.uk/20100304104942/http://www.berr.gov.uk/files/file36128.pdf. Last accessed 16th May 2015.

EGAN, J. (1998). *Rethinking Construction: The Report of the Construction Task Force* HMSO, Her Majesty's Stationary Office, London.

FILLIBEN, J.J. (2012). *Confidence Limits for the Mean* [online] Available from http://www.itl.nist.gov/div898/handbook/eda/section3/eda352.htm. Last accessed 23rd April 2015.

FISHBACH, A., KOO, M. AND FINKELSTEIN, S.R. (2014). *Motivation Resulting from Completed and Missing Actions*, in: J. Olson and M.P. Zanna (Eds.) Advances in experimental social psycholog*y*, Vol 50 (2014): 257-307.

FORD, H. AND CROWTHER, S. (1926). *Today and Tomorrow*. Garden City, New York, USA

GILBRETH, F. (1974). *Bricklaying System*. Hive Publishing (reprint), Easton, PA.

GILBRETH, F. JR. AND GILBRETH, E.C. (1948). *Cheaper by the Dozen*. Bantam Books, New York.

GLENIGAN. (2014). *Construction Statistics - No. 15, 2014 Edition* [online] Available from https://www.glenigan.com/market-analysis/reports/construction-kpi-report-2014. Last accessed 3rd May 2015.

GOLDRATT, E.M. AND COX, J. (2004). *The Goal: A Process of Ongoing Improvement*. North River Press, Great Barrington, MA.

GOODSON, R. (May 2002). *Tool Kit: Read a Plant* - Fast. Harvard Business Review May 2002: 105-113.

GRAUPP, P. AND WRONA, R. (2006). *The TWI Workbook: Essential Skills for Supervisors*. Productivity Press, New York.

GREEN, S.D. (1999). *The dark side of lean construction: exploitation and ideology*, in: I. D. Tommelein (Ed), Proceedings of the 7th Conference of the International Group for Lean Construction (IGLC-7), University of California, Berkeley: 21-32.

GREEN, S.D. AND MAY, S.C. (2005). *Lean construction: Arenas of enactment, models of diffusion and the meaning of 'leanness'*. Building Research and Information, Vol 33(6): 498-511.

HENDERSON, B.A. AND LARCO J.L. (2003). *Lean transformation: How to change your business into a lean enterprise.* The Oaklea Press, Richmond, VA.

HOLBROOK, M.C., GREEN, J. AND KROSNICK, A. (2003). *Telephone Versus Face-To-Face Interviewing Of National Probability Samples With Long Questionnaires*. Public Opinion Quarterly, Vol 67: 79–125.

HORNER, R.M.W. AND DUFF, A.R. (2001). *More for less - A contractor's guide to improving productivity in construction*. CIRIA, London.

HOWELL, G. (1999). *What is Lean Construction*. Lean Construction Institute.

HOWELL, G.A., MACOMBER, H., KOSKELA, L. AND DRAPER, J. (2004). *Leadership and Project Management: Time for a shift from Fayol to Flores*. Proceedings of the 12th Annual Meeting of the International group for Lean Construction, Helsingør, Denmark: 22-29.

ISO 18404 (2015) *Quantitative methods in process improvement -- Six Sigma -- Competencies for key personnel and their organizations in relation to Six Sigma and Lean implementation*. Available from http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=62405 Last Accessed 16-01-2016

JAMIESON, S. (2004). *Likert scales: How to (ab)use them*. Medical Education, Vol 38: 1217–1218.

JURAN, J.M. AND GODFREY, A.B. (2000). *Juran's Quality Handbook*. McGraw-Hill, New York.

KOHN, A. (1999). *Punished by Rewards: The Trouble with Gold Stars, Incentive Plans, A's, Praise, and Other Bribes*. Houghton Mifflin.

KOSKELA, L. (1992). *Application of the New Production Philosophy to Construction*. Technical Report 72, CIFE Centre for Integrated Facility Engineering, Stanford, California.

KOSKELA, L. (2000). *An exploration towards a production theory and its application to construction* – PhD thesis Helsinki University of Technology, Helsinki.

KOSKELA, L. (2004a). *Moving on – beyond lean thinking*. Lean Construction Journal Vol 1(1): 24-37.

KOSKELA, L. (2004b*). Making do - the eighth category of waste*. 12th International Group for Lean Construction Conference. Elsinore, Denmark.

LEONG, M.S., WARD, S. AND KOSKELA, L. (2015). *Towards an operational definition of lean construction*, in: Proceedings of the 23rd Annual Conference of the International Group for Lean Construction. Perth, Australia, July 29-31: 507-516

LICHTIG, W. (2005). *Ten Key Decisions to A Successful Construction Project*. American Bar Association, Forum on the Construction Industry. Toronto, Canada.

LIKER, J. (2004). *The Toyota Way: 14 management principles from the world's greatest manufacturer*. McGraw-Hill, New York.

LIKER, J., AND T. LAMB. (2000). *Lean Manufacturing Principles Guide. A Guide to Lean Shipbuilding*. (University of Michigan, Ann Arbor, Michigan)

MANAGEMENT LIBRARY, (2012*). Frank and Lillian Gilbreth* [online] Available from http://www.vectorstudy.com/management-gurus/frank-and-lillian-gilbreth. Last accessed 15 August 2015.

MAROSSZEKY, M. AND KARIM, K. (1997). *Benchmarking - a Tool for Lean Construction*, 5th Annual Conference of the International Group for Lean Construction 1997: 157-167.

MASTROIANNI, R. AND ABDELHAMID, T.S. (2003). *The Challenge: The Impetus For Change To Lean Project Delivery*. Proceedings of the 11th Annual Conference for Lean Construction, 22-24 July 2003. Blacksburg, Virginia: 610-621.

MCDONALD, J.H. 2014. *Handbook of Biological Statistics* - 3rd edition. Sparky House Publishing, Baltimore, Maryland.

MITROPOULOS, P. AND HOWELL, G. (2001). *Performance Improvement Programs And Lean Construction,* Proceedings of the 9th Annual Meeting of the International group for Lean Construction. Singapore.

NEW WORLD ENCYCLOPEDIA CONTRIBUTORS, 2013. *Frank and Lillian Gilbreth* [online] Available from http://www.newworldencyclopedia.org /p / index.php? title=Frank_and_Lillian_Gilbreth&oldid=977037. Last accessed 15th August 2015.

NHS MODERNISATION AGENCY, 2002. *Improvement leaders' guide to sustainability and spread*. Ancient House Printing Group, Ipswich, England.

NORMAN, G. 2010. *Likert scales, levels of measurement and the "laws" of statistics*. Advances in Health Sciences Education, Vol 15(5): 625-632.

OHNO, T. (1988). *Toyota Production System: Beyond Large-Scale Production*. Productivity Press, Cambridge, MA.

OPDENAKKER, R. (2006). *Advantages and disadvantages of four interview techniques in qualitative research*. Forum Qualitative Sozialforschung, 7(4) 2006 [online] Available from http://www.qualitative-research.net/index.php/fqs/article/ view/175. Last accessed 15 May 2015.

PAPPAS, P.A. AND DEPUY, V. (2004). *An Overview of Non-Parametric Tests in SAS®: When, Why, and How* in Proceedings in SouthEast SAS Users Group Conference: paper TU04.

PETTERSEN, J. (2009). *Defining lean production*: Some conceptual and practical issues. TQM Journal, Vol 21(2): 127-142.

PYZDEK, T. (2003). *The Six Sigma Handbook*. McGraw-Hill Companies, New York.

RHODES, C. (2015). *Construction industry: statistics and policy* [online] Available from http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN01432. Last accessed 16th June 2015.

RICCI, T. (2012). *Frank Bunker Gilbreth* [online] Available from https://www.asme.org/engineering-topics/articles/construction-and-building/frank-bunker-gilbreth. Last accessed 15th August 2015.

RYBKOWSKI, Z.K., ABDELHAMID, T.S. AND FORBES, L.H. (2013). *On the back of a cocktail napkin: An exploration of graphic definitions of Lean Construction*, 21st Annual Conference of the International Group for Lean Construction 2013, IGLC 2013: 984-993.

SALEM, O., SOLOMON, J., GENAIDY, A. AND LUEGRING, M. (2005). *Site Implementation and Assessment of Lean Construction Techniques*. Lean Construction Journal, Vol 2(2): 1-21.

SAMSON, D. AND TERZIOVSKI, M. (1999), *The relationship between total quality management practices and operational performance*. Journal of Operations Management, Vol. 17(4): 393-409.

SEDDON, J. (2003). *Freedom from Command and Control: a better way to make the work work*. Vanguard Press.

SENGE, P.M. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization*. Doubleday/Currency.

SEXTON, S. (2014). *Intel Ireland Collaborate with Construction Partners to Host Lean Construction Expo* [online] Available from http://newsroom.intel.com/community/en_ie /blog/2014/12/04/intel-ireland-collaborate-with-construction-partners-to-host-lean-construction-expo. Last accessed 16th August 2015.

SHEWHART, W. (1931). *Economic control of quality of manufactured product*. D. Van Nostrand Company, New York.

SHEWHART, W.A. (1924-1958). *The Bell System Technical Journal* Alcatel-Lucent Journal [online] Available from http://ieeexplore.ieee.org Last Accessed 15th August 2015.

SHEWHART, W. A. (1939). *Statistical method from the viewpoint of quality control*. Washington, D.C., The Graduate School, the Department of Agriculture ISBN 0-486-65232-7.

SHINGO, S. (1985). *A Revolution in Manufacturing: The Smed System*. Productivity Press, New York.

SHINGO, S. (2007). *Kaizen and The Art of Creative Thinking*. PCS Inc, Vancouver.

SMITH, K. (2007). *Presentation to the International Group for Lean Construction*. IGLC Salford, Manchester, UK.

SMITH, M.K. (2011). *Common Mistakes In Using Statistics: Spotting and Avoiding Them* [online] Available from https://www.ma.utexas.edu/users/mks/statmistakes/StatisticsMistakes.html Last accessed 24th April 2015.

SOWARDS, D. (2004). *5S's that would make any CEO Happy*. Contractor Magazine, Vol 51(6) The Newsmagazine of the Mechanical Contractor's Association. Penton Media, New York, NY. Jun. 2004.

SPEAR STEVEN J. (2004). *Learning to lead at Toyota.* Harvard Business Review, 82 (5), pp. 78-86+151

SPEAR, S. J. AND BOWEN, H,K. (1999). *Decoding the DNA of the Toyota Production System* – Harvard Business Review, 77 (9/10) (1999), pp. 97–106

STEVENS, M. (2014). *Increasing adoption of lean construction by contractors*, 22nd Annual Conference of the International Group for Lean Construction: Understanding and Improving Project Based Production, IGLC 2014: 377-388.

TAYLOR, F.W. (1911). *The Principles of Scientific Management*. Harper & Brothers, New York, NY.

UEBERSAX, J.S. (2006). *Likert scales: dispelling the confusion* [online] Available from http://john-uebersax.com/stat/likert.htm. Last accessed 3rd April 2015.

VAILLANCOURT, R. (2009). *I Hear and I Forget, I See and I Remember, I Do and I Understand* [online] Available from http://www.ncbi.nlm.nih.gov/pmc/articles /PMC2826962/. Last accessed 16th May 2015.

VRIJHOEF, R. & KOSKELA, L. (2005), *'Revisiting the Three Peculiarities of Production in Construction'* In:, 13th Annual Conference of the International Group for Lean Construction. Sydney, Australia, 19-21 Jul 2005. pp 19-27

WARD, S. A. AND MCELWEE, A. (2007). *Application of the principle of batch size reduction in construction*. Paper presented at the Lean Construction: A New Paradigm for Managing Capital Projects - 15th IGLC Conference: 539-548.

WOLSTENHOLME, A. (2009). *Never Waste a Good Crisis. A Review of Progress since Rethinking Construction and Thoughts for Our Future.* Constructing Excellence, London

WOMACK, J.P., JONES, D.T. AND ROOS, D. (1990). *The Machine that Changed the World*. Rawson Associates, New York, NY.

WOMACK, J.P. AND JONES, D.T. (1996). *Lean Thinking - Banish Waste and Create Wealth in your Corporation*. Simon & Schuster, London.

WOODBURY, R. (1960). *The Legend of Eli Whitney and Interchangeable Parts*. Technology & Culture, Vol 1(3): 235-253.

ZOKAEI, K., ELIAS, S., O'DONAVAN, B., SAMUEL, D., EVANS, B. AND GOODFELLOW, J. (2010). *Lean and Systems Thinking in the Public Sector in Wales*: Report for the Welsh Audit Office Cardiff: Lean Enterprise Research Centre

BIBLIOGRAPHY

The following references were read by the author to enhance knowledge of the research area but not directly referenced

ABDELHAMID, T.S. (2004). *The Self-Destruction and Renewal of LEAN CONSTRUCTION Theory: A Prediction From Boyd's Theory*. 12th Annual Conference of the International Group for Lean Construction. Helsingør, Denmark.

BALLARD, G. (1994). *The Last Planner*. Northern California Construction Institute Spring Conference. Monterey.

BALLARD, G. AND HOWELL, G. (1998). *Shielding Production: Essential Step in Production Control*. Journal of Construction Engineering and Project MAnagement , Vol. 124(1): 11-17.

BALLARD, G. AND HOWELL, G, A. (2003). *Competing Construction Management Paradigms*. ASCE Construction Research Congress. Honolulu, Hawaii.

CAIN, C. (2003). *Building Down Barriers - A Guide to Construction Best Practice*. Taylor and Francis, New York.

CAIN, C. (2004a). *Performance Measurement for Construction Profitability* – 1st Edition. Wiley-Blackwell

CAIN, C. (2004b). *Profitable Partnering for Lean Construction*. Wiley-Blackwell.

CAMERON, O. (2005). *Lean Leadership in Construction*, Proceedings from the 13th Annual Meeting of the International Group for Lean Construction. Sydney, Australia: 345-351.

MORTON, R; ROSS, A;. (2007) *Construction UK: Introduction to the Industry* - 2nd Edition. Wiley-Blackwell.

HENDRICKS, K.B. AND SINGHAL, V.R. (2001). *The long-run stock price performance of firms with effective TQM programs*. Management Science, 47(3): 359-368.

KOSKELA, L. AND HOWELL, G. (2002). *The Underlying theory of Project Management is Obsolete*. Proceedings of the Project Management Institute Research Conference: 293-302

KOSKELA, L., HOWELL, G., BALLARD, G. AND TOMMELEIN, I. (2002). *The Foundations of Lean Construction*, in: Best, R. and de Valence, G. (Eds). Design and Construction: Building in Value. Butterworth-Heinemann, Elsevier, Oxford, UK.

PORTER, M. (2008). *The five competitive forces that shape strategy*. Harvard Business Review 86(1*)*: 79-93, 137.

SOWARDS, D. (2004). *5S's that would make any CEO Happy*. Contractor Magazine, Vol51 (6) [online] Available from http://contractormag.com/technology/ cm_ newsarticle_456. Last accessed 8 May 2015.